CIRCULAR 6169 SEPTEMBER, 1929

DEPARTMENT OF COMMERCE

UNITED STATES BUREAU OF MINES
SCOTT TURNER, DIRECTOR

RECEIVED
OCT 1929
O. U. LIBRARY

INFORMATION CIRCULAR

MINING PRACTICE AND METHODS AT INSPIRATION CONSOLIDATED COPPER COMPANY INSPIRATION, ARIZONA

BY

ALFRED C. STODDARD

Circular 6169
September, 1929.

INFORMATION CIRCULAR

DEPARTMENT OF COMMERCE - BUREAU OF MINES

MINING PRACTICE AND METHODS AT INSPIRATION CONSOLIDATED COPPER CO., INSPIRATION, ARIZ.[1]

By Alfred C. Stoddard[2]

INTRODUCTION

This paper describing the mining practices of the Inspiration Consolidated Copper Co. at Inspiration, Ariz., is one of a series being prepared by the Bureau of Mines on mining practices, methods, and costs in the various mining districts of the United States.

HISTORY

The history of mining in the Globe-Miami District starts in the seventies, when prospectors began roaming the hills of central Arizona. The Silver King on the south side of the Pinal Mountains and the first claims of the present Old Dominion property at Globe on the north side of the range were located about 1875. Only silver and gold ores were valuable in those early days, as copper was too bulky a product to be shipped to the areas of consumption. In the late eighties, however, small reduction plants for treating high-grade copper ore were built in the Globe district, blister copper being shipped east for refining. The green and blue outcrops in the hills to the west of Globe surely intrigued those early seekers of high-grade ores, and no doubt small amounts from there were treated at the Globe smelters. Old workings show that some silicate copper ores were mined from veins outcropping in the hills where the present Live Oak and Keystone sections of the Inspiration Consolidated Copper Co. are located. The tonnage so extracted is not known.

In the early part of the present century Bud Woodson, John Copeland, Jack Neuman, and others were prospecting in the Miami hills. The best ore was found in the Black Warrior and Black Copper properties. It may be of interest to note that Colonel Fleming was conducting leaching experiments on Black Warrior ore shortly after 1900. Exploration work was continued at other places and eventually tunnels driven into the north side of Inspiration Ridge reached low-grade sulphide ore. This seemed a poor reward for years of effort, but was the original discovery of the large low-grade ore bodies of the Miami district.

---

[1] The Bureau of Mines will welcome reprinting of this article provided the following footnote acknowledgment is used: "Reprinted from U. S. Bureau of Mines Information Circular 6169."

[2] One of the consulting engineers, U. S. Bureau of Mines, and Chief Mine Engineer, Inspiration Consolidated Copper Co.

In a few years the success of the Utah Copper Co. and the Nevada Consolidated Copper Co. caused a search for other similar deposits, and then the Miami district came into its own as a potential source of large-scale copper production.

Intensive development and construction started in the Miami end of the district in 1908. Churn-drill exploration of the Inspiration end started in 1910 and underground development was well under way in 1911. Construction of treatment plants was finished far enough so that on July 1, 1915, the Inspiration Consolidated Copper Company was officially placed in production. A leac ing plant for the treatment of oxidized ores was completed in 1927.

PRODUCTION

In 1928 the production of the mine was 4,879,646 tons of ore averagin 1.125 per cent copper. Of this amount 1,838,164 tons was concentrating and smelting ores assaying 1.296 per cent copper, and 3,041,482 tons was leaching ore carrying 1.022 per cent copper. The copper production for the year was 88,123,311 pounds, of which 38,313,520 pounds was from concentrating ores, 49,692,724 from leaching ores, and 117,067 from direct smelting ores.

The total production of the mine from the start of operations to the end of 1928 has been 1,083,183,258 pounds of copper.

The mine is operated during three 8-hour shifts per day, employing a total of 1,750 men.

GEOLOGY

The disseminated ore of the Miami district occurs in two formations - the Pinal schist and Schultz granite. The grade of the ore is no higher in one than in the other. The mineralization in both the granite and the schist is abruptly cut off on the east by the Miami fault. On the west in Live Oak ground the ore body becomes too thin to be mined profitably. Both on the nort and south faulting partly limits the ore body; there is also in places a gradual reduction of the grade of the ore to material too low-grade to be mine Part of this low-grade material may be ore in the future.

The only large displacement of the present ore body (see fig. 1) is b the Bulldog fault, which strikes north and south and dips to the east. This fault drops the west end of the Inspiration ore body in relation to the east end of the Live Oak ore body, but has not materially affected mining methods or development of the areas.

In general, the bottom of the ore body is reasonably regular, either flat or dipping on such a slope that considerable areas can be reached from one haulage level without unduly long raises.

The total length of mineable ores in the ground of Inspiration Consolidated Copper Co. is about 8,000 feet, with an average width of 800 feet and an average thickness of 200 feet.

In some places the ore outcrops on the surface, and elsewhere the capping varies to a maximum thickness of 500 feet.

The chief copper minerals are chalcocite, malachite, azurite, and chrysacolla, and these minerals are usually distributed along cracks and fractures and in the crevices. In some locations, however, little specks of chalcocite are distributed throughout the rock. Quite often in the chalcocite ores residual particles of pyrite can be seen and in the mixed ores part of the sulphide remains unchanged.

No doubt it is the fractures that make the Inspiration ore bodies mineable by a caving system.

PROSPECTING AND SAMPLING

The probable and possible ore-bearing areas of the various divisions of the company's property were explored and prospected by churn-drilling; the holes were put down wherever practical on the corners of 200-foot squares.

The original churn-drill sampling was done in as careful a manner as possible. From each 5-foot interval the sludge was bailed and run through a splitter, the sample going into a tub. At this time the sample was examined for its mineral constituents, and the results were placed on the log sheet. If the examination seemed to show a preponderance of copper sulphide, the ore was classed as "sulphide"; if oxides and carbonates were mixed with the sulphides, it was shown as "mixed"; and if only the oxides and carbonates showed, it was marked "carbonate."

This classification was done with care, but it can be assumed that "sulphide" was favored slightly, as this was at the time the only ore of economic value. Toward the end of the churn-drilling period, while the samples were still classified according to their visible mineral constituents, they were also assayed for acid soluble and insoluble copper. This was a tremendous step in truly classifying the ore.

The sludge in the tub was brought to dryness over an open fire. If the sampler were careless and dried and heated the sample too much, probably some oxidation took place and the sulphide got the worst of it.

In recent drilling the sample has been taken in the same way, but has been brought to dryness on a steam sample-drier and the dried sample assayed for acid soluble and insoluble copper.

In the last few years considerable diamond drilling has been done, particularly to determine the class of ore, whether sulphide or oxide, and also to determine accurately the bottom of the ore bodies. In addition, some prospect drilling has been done with the diamond drill. In accuracy, speed, and cost diamond-drilling compares most favorably with churn-drilling.

ESTIMATION OF TONNAGE

The tonnage estimates were made on the basis that 12-1/2 cubic feet of ore in place would equal 1 ton. As the drilling was done on the corners of

200-foot squares, it was usual to take 40,000 square feet as a unit. In a fe instances an area of one-half a unit was used, and also in a few instances the area was calculated, due to irregular spacing of the drill holes.

The ore was classified through various gradations from low carbonate to low sulphide. The footage of each class of ore in each drill hole was ta and the sum of these footages in the four holes of the quadrilateral was divi by four to get an average footage or thickness of ore in the quadrilateral. This average footage multiplied by the area of the block gave the cubic feet of the class of ore in the block; and this amount when divided by 12-1/2 gave the tonnage of each class. Summing up the block tonnages gave the total ton-nage of ore of each class.

The grade of the ore in an area was computed by taking the sum of the assays for each of the four holes, considering each class of ore separately, and dividing by the number of assays to get the average value. This averag value of each class of ore in each hole was then multiplied by the footage to get a result in feet per cent. The feet per cent of the four holes was summed and divided by the total footage to give an average value for the area. The tonnages and grades of the individual blocks were combined to give a total tonnage and grade for the property of each class of ore. The classes of ore were finally combined to give a total tonnage and grade for all the ores.

To check this estimate the same method of computation was used on all the ore without regard to class to arrive at a total tonnage and grade.

Subsequent to these estimates, another estimate was made from sections

Judging from the experience of other companies under similar conditi the results of the churn-drilling were considered sufficiently accurate to jus fy the spending of hugh sums for mining development and plant construction, and no underground work was done to check the churn-drilling until actual mini operations were ready to begin. However, early in the development of the In-spiration division ore body there was an opportunity to check by means of dri and raises a considerable area that had been drilled. The check of the estima made from the drill samples against two sets of mine samples was remarkably close.

In the light of subsequent events perhaps this checking was done under the most favorable conditions. Still, the knowledge gained from mining areas which probably would not have checked so well has now made it possible to weig the reliability of churn-drill sampling as a method for estimating the grade and tonnage of an ore body.

The original tonnage and grade estimates were made by the engineering staffs of the Live Oak Development Co. and the Inspiration Copper Co. from tim to time. The study of the churn-drill records in connection with underground mining operations has always been used to guide the planning of future develop-ment work.

DEVELOPMENT AND MINING

The churn-drilling, in a general way, had definitely located the bottom of what was then considered the profitable ore horizon. Certain areas were available for steam-shovel mining, but it was considered that underground methods were more applicable to the whole ore body.

Elaborate studies by means of models were made of caving operations. Close estimates of costs were worked out and it was decided to mine the Inspiration division ore bodies by the mining method put into practice by Mr. Felix McDonald at the Ohio Copper Co.'s mine. This method had the merit of giving a low cost per ton and it was thought that controlled drawing would give the greatest and quickest returns on the money invested in the property.

After being undercut the ore is drawn from control chutes through grizzlies and into storage raises. From these raises it is loaded into cars on the haulage level and taken to the shaft.

Development

Figures 1 and 2 show the ore body and the major development workings of the mine. The mine is operated as three separate divisions - the Inspiration, the Live Oak, and the Keystone. For some purposes the two latter divisions are treated as a unit. The Inspiration division was the original mine. The Live Oak was next developed. The ore from this division is hoisted in the Live Oak shaft and shipped by rail to the primary crushing plant at the Inspiration hoisting shafts. From here it is taken to the concentrator. The Keystone division is developed through an adit known as the Sulphide tunnel, its ore, however, being hauled underground to the Inspiration shaft and there hoisted. Most of this ore is treated in the leaching plant.

As must be realized, any large tonnage method of mining necessitates unusually good underground haulage systems; for the "throat" of the whole scheme is getting the ore from the mining areas to the hoisting shafts. The hoisting shafts must be located far enough outside the mining areas to be safe from disturbance. This entails long haulage distances on each haulage level. Therefore, the considerable cost of each additional haulage level must be carefully balanced against the cost of raising necessary to reach the bottom of the inclined parts of an ore body.

Inspiration Division. - The original plan of development of the Inspiration division called for a main haulage level (the 600) 450 feet below the collar of the ore hoisting shafts, and a secondary haulage level, the 400. Sublevels were driven at approximately 30-foot vertical intervals.

Three shafts were sunk to facilitate this development work. The Joe Bush was used principally for sublevel development and for driving the 400 haulage level. The Scorpion and Colorado were sunk to the 600 level. From them this level was extended to the limits of the Inspiration division, and eventually a connection was established with the Live Oak and Keystone divisons.

From a sublevel an inclined shaft (fig. 3) was raised to the surface and sunk to the sixth level. A small amount of development work was done from this shaft, but its principal use has been as an entrance through which to bring supplies into the mine.

To date the Inspiration division has had three very extensive haulage levels, the 400, 600, and 850. The 400 is now worked out and abandoned, the 600 is nearly finished, and the 850 is being developed and is producing ore.

Live Oak and Keystone Divisions. - The planning of the development of the Inspiration division was easy compared with that of the Live Oak division.

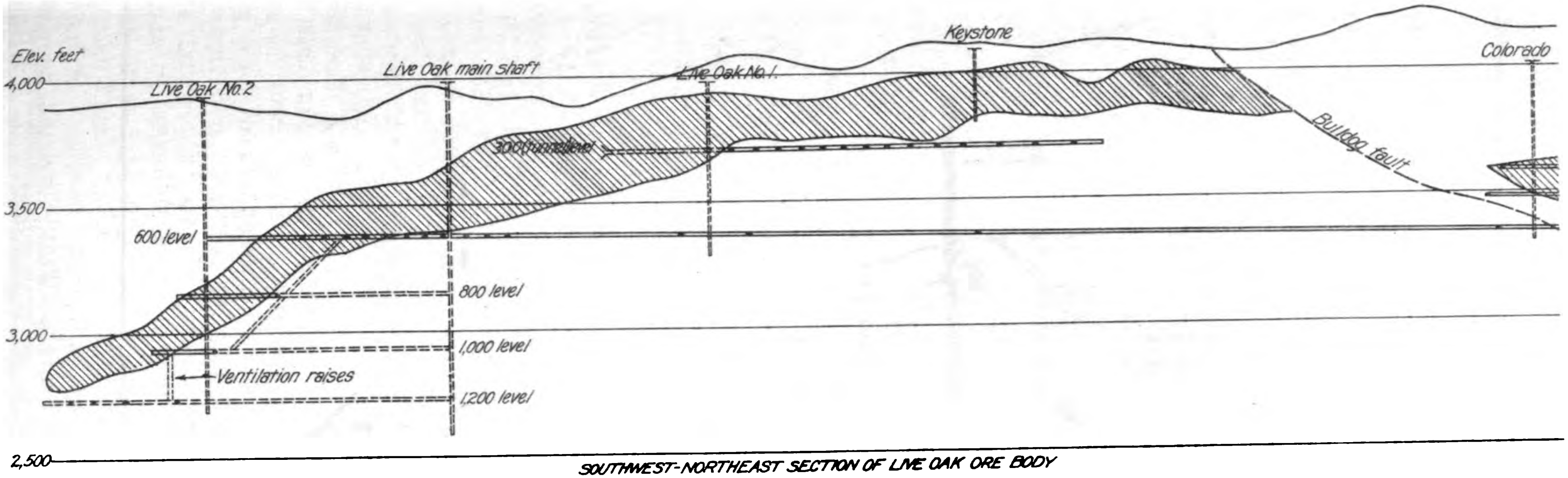
This division, together with the Keystone, covers an extreme length of 4,000 feet. On the east end the ore outcrops; on the west it is covered wit 500 feet of capping, and the bottom is lower by 900 feet. If this 900 feet of drop had been on an even grade throughout the 4,000 feet, it would not have be so difficult. Instead, the bottom of the ore was reasonably flat for considerable distances, then pitched on a 45° slope for several hundred feet, and then flattened out again. This condition necessitated careful study of the haulage level locations.

The Live Oak division is developed and operated through the Main Live Oak shaft. A second shaft is used as an upcast air course. Four levels, the 600, 800, 1,000 and 1,200, have been developed. The ore dips away from the shaft, which increases the length of haul on lower levels.

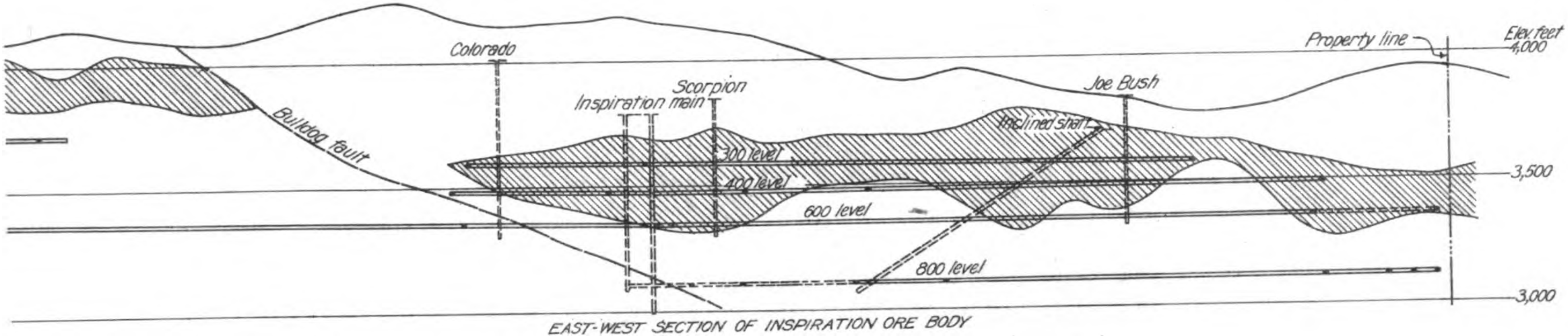
The main haulage level of the Keystone division is the 300, or Sulphid Tunnel level. Ore gathered on this level is dropped through storage pockets to the 600 level and hauled to the Inspiration shafts.

Two shafts which served in the early development of the Live Oak-Keystone ore body are now used as ventilating shafts.

Hoisting Shafts. - In addition to the development shafts, twin operati shafts were sunk on the Inspiration end of the property. This was done as soo as the Inspiration division ore body was proved to be of economic importance. These shafts are north of the ore body, sufficiently far from it to be safe from caving operations, and are fairly centrally located with respect to the haulage of ores. They are identical in size and 104 feet apart. They were timbered with light timbers as sunk, and were concreted from the bottom up (see fig. 4). The stations and pockets were excavated and concreted as the concreting of the shaft was brought up. As completed, each shaft had three compartments, two in each shaft being used for ore skips. The third compartme in one shaft was used for a double-deck passenger elevator; this has been used through the years as the means for the various working crews to enter and leave the mine. In the other shaft the third compartment served as a passageway for the cage counterbalance as well as for pump columns, mine water-supply lines, high and low-pressure air lines and electric cables. The usual ladderway was also provided in this compartment. The three compartments in each shaft were identical in size; that is, 5 feet 6 inches at right angles to the guides and 5 feet 11 inches parallel to the guides. This size of shaft compartment permitted the use of a large skip, the inside area of the latter being approximately 20 square feet and the depth 14 feet. This skip was supposed to have a



SOUTHWEST-NORTHEAST SECTION OF LIVE OAK ORE BODY



EAST-WEST SECTION OF INSPIRATION ORE BODY

Figure 1.- Sections of Live Oak and Inspiration ore bodies, showing shafts and haulage levels
Vertical and horizontal scales the same

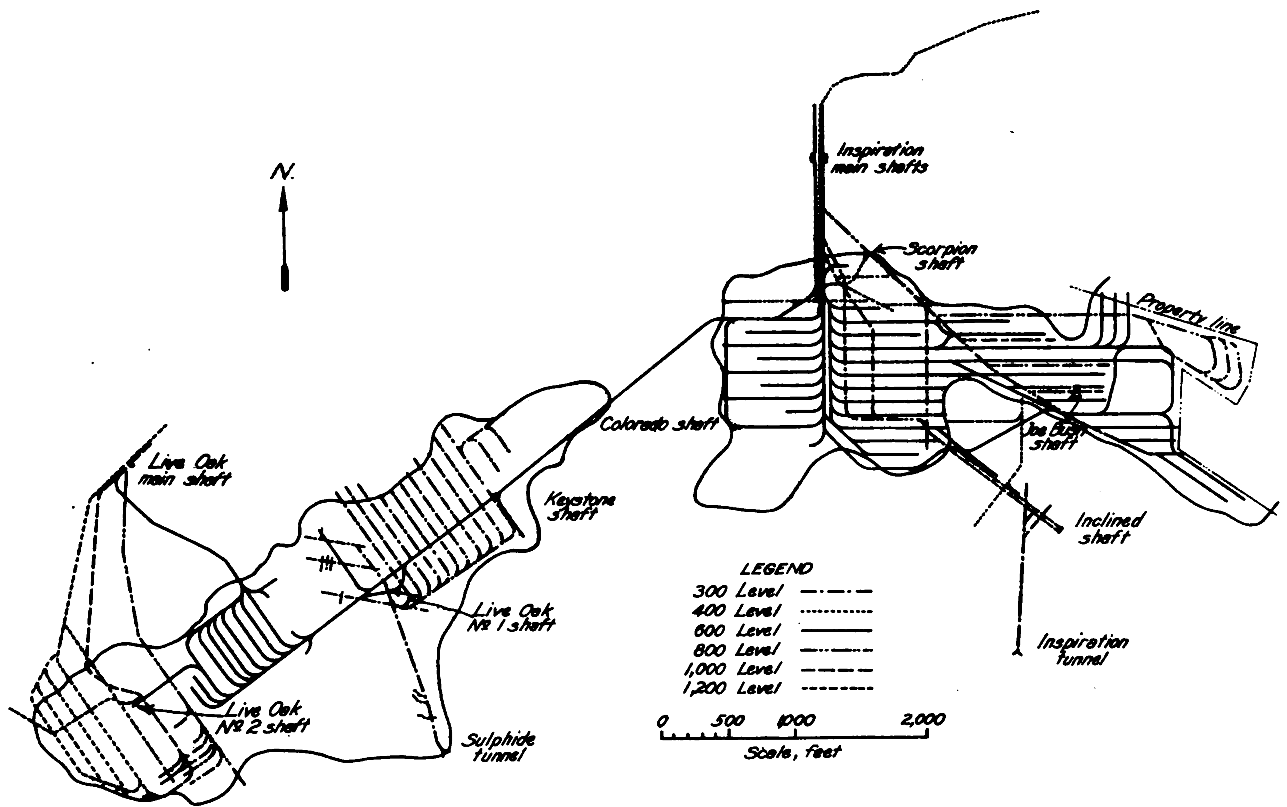


Figure 2.- Plan of ore bodies, shafts, and haulage levels

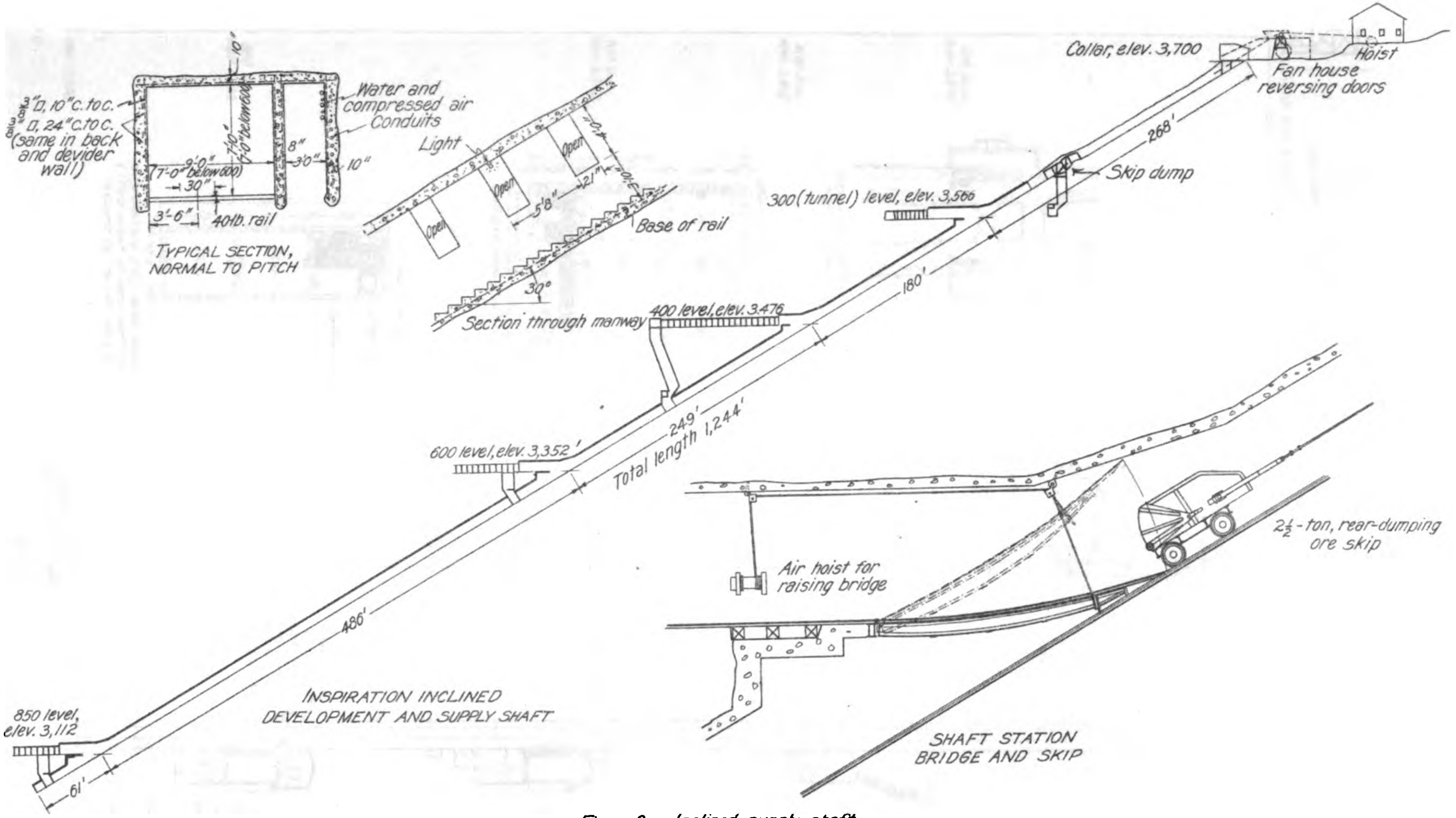

10"
$\frac{3}{8}$" □, 10" c. to c.
$\frac{3}{8}$" □, 24" c. to c. (same in back and devider wall)
Water and compressed air Conduits
7'-10" 5'-0" below 600
9'-0" (7'-0" below 600)
8"
3'0"
10"
30"
3'-6"
40 lb. rail
TYPICAL SECTION, NORMAL TO PITCH
Light
Open
Open
Open
4'0"
21"
3'10"
5'8"
30°
Base of rail
Section through manway
Collar, elev. 3,700
Hoist
Fan house reversing doors
268'
Skip dump
300 (tunnel) level, elev. 3,566
180'
400 level, elev. 3,476
249'
Total length 1,244'
600 level, elev. 3,352
486'
850 level, elev. 3,112
61'
INSPIRATION INCLINED DEVELOPMENT AND SUPPLY SHAFT
Air hoist for raising bridge
$2\frac{1}{2}$-ton, rear-dumping ore skip
SHAFT STATION BRIDGE AND SKIP

Figure 3. - Inclined supply shaft

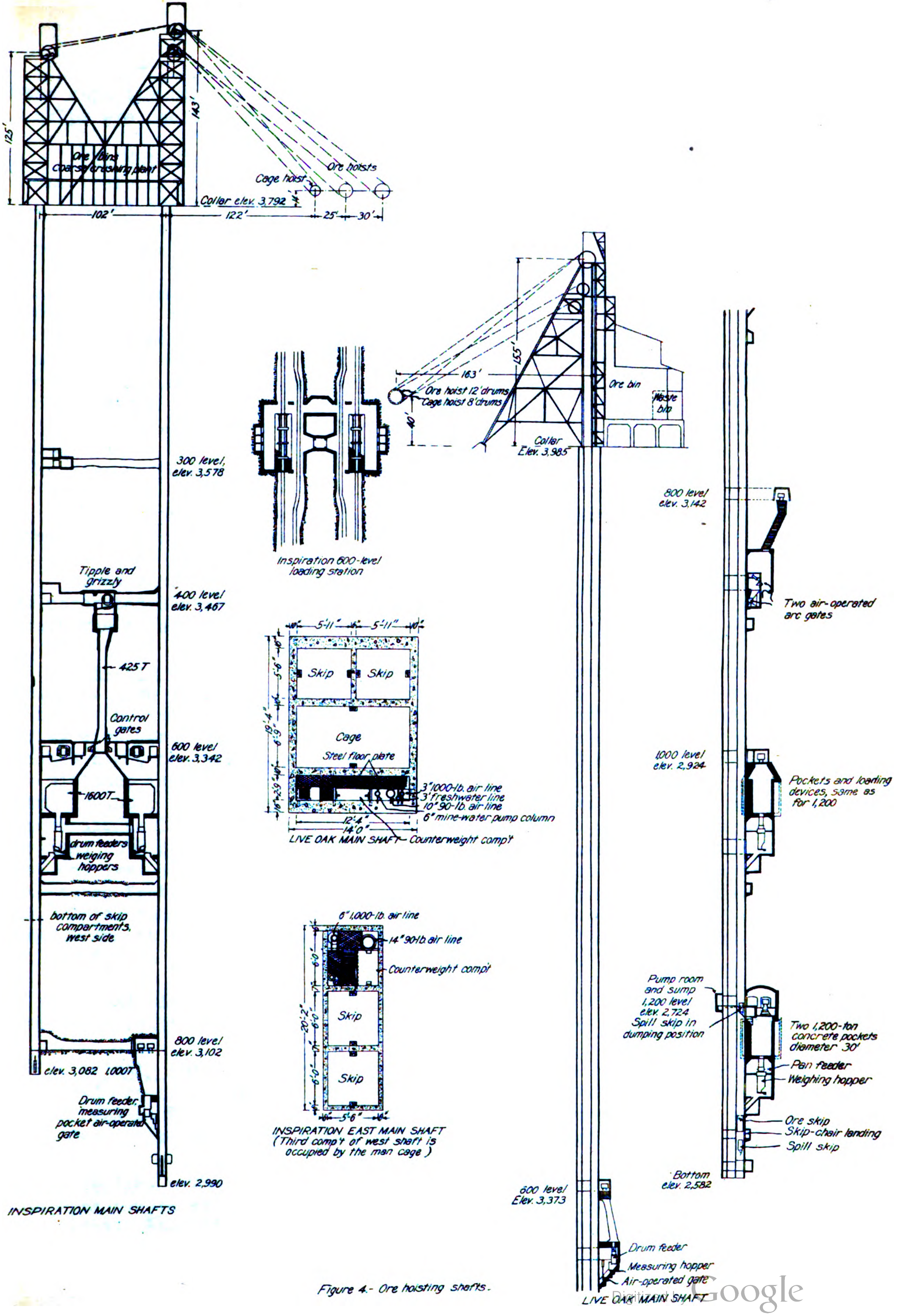


Figure 4.- Ore hoisting shafts.

12-ton capacity but holds a larger load. The usual load is kept at 12-1/2 tons. The skips are operated in balance.

The Main Live Oak shaft (fig. 4) was sunk at a considerably later date and due to local conditions was of a different section. The depth was 1,400 feet, against 585 feet at Inspiration; a separate supply entrance was not possible. The skip compartments were made the same size as at the Inspiration shafts. The man-cage compartment was made 6 feet 9 inches by 12 feet 4 inches. This size permitted a cage of such dimensions that 5-ton mine cars could be transferred from level to level; trucks holding ordinary mining timbers could be lowered from the surface to the various levels, and approximately 55 men could be hoisted or lowered at one time. An innovation applied to both the Inspiration elevator and the Live Oak main shaft cage was an insulated cable hanging from the cage to a junction box in the shaft wall midway in the travel. This carried telephone wires for connection with the various levels, surface, and hoist engineer's platform. It also permitted flashing of signals to the attendant whether the cage was in motion or stationary and allowed electric lights to be installed on the cage and elevator.

The compartment for the ladderway, cage counterweight, pipes, and conduits at the Live Oak shaft is 2 feet 9 inches by 12 feet 4 inches.

This shaft was concreted from the bottom up, and stations and pockets were concreted during the progress of the shaft work. The excavation of the pockets was done in most instances after the concreting.

Haulage drifts. - The size of haulage drifts has been standard since operations were started. The cap of a timber set is 7 feet 6 inches in the clear. By a State statute the distance from the top of the track ties to a trolley wire must be at least 7 feet. Inasmuch as trolley hangers are about 4 inches high, the distance there became 7 feet 4 inches from tie to cap. This distance is set at 7 feet 6 inches by the company, and 8-foot posts are generally used; at times posts 8 feet 6 inches long were used on the ditch side. As more difficult rock conditions were encountered, the length of the posts was increased to 9 feet and the height above the base of rail was increased to 8 feet, and even to 8 feet 6 inches. Originally the batter on the posts was 1 inch to the foot, but standard practice has been changed to 1-1/2 inches per foot. This change increased the clearance between cars and timber; also, in heavy ground it increased the length of service time before posts had to be "set back", and perhaps made a stronger drift section.

Sawed timber has been used almost entirely in the mine. Underground storage difficulties are the chief drawback in the use of poles or round timber.

Grizzly and Undercutting Drifts. - Grizzly and undercutting drifts when untimbered are driven 4 by 6 feet to 5 by 7 feet in section, with the usual rounded crown. When timbering is necessary a standard small drift set is used with a cap 3 feet 6 inches in the clear and with 7-foot posts.

Raises. - The sections of primary ore passes have been of different sizes when driven without timber, varying within the limits of 3 by 3 feet to 5 by 7 feet. When timbered the sizes for many years have been standard at 4 by

4 feet, 3 by 3 feet, and 3 by 4 feet in the clear. Sections other than squa are higher than wide. Raises are cribbed and the upper and sometimes lower corners of the individual timbers at places of maximum wear are protected by 3/8 by 3-1/2 by 3-1/2 inch angle irons. Various sizes of cribbing timber ha been used, but the standard for a long time has been 6 by 10 inch. When a timber 6 by 10 inches by 5 feet long (a 4-foot cribbing) is angle-ironed, it is about the right weight to handle up raises. An 8 by 10, or 6 by 12 inch piece similarly ironed is too heavy, and smaller sizes do not have sufficient strength to hold the ground.

Transfer ore passes from haulage level to haulage level usually have section of 6 by 8 feet in the clear. They are timbered with 10 by 10 inch cribbing, angle-ironed both top and bottom, and placed flush on each other. The placing of timbers skin to skin is the result of experience, as in the early days sets lined with plank were tried unsuccessfully in raises.

In some areas independent supply and manway raises have been driven, but usually a raise in mined-out country or ore that is ready in advance of mining is used for a manway and for bringing in supplies. Supplies are hoist in a metal "boat", using air-driven hoists.

Drilling. - Medium-weight drifters and wet pluggers and stopers are for drilling the widening and undercutting rounds. The same types of drifter and plugger are used for large and small drift work. Medium-weight pluggers are used for shaft-sinking. For raise work a wet hand-rotated medium-weight stoper is used.

While numerous types and makes of machines have been tried, it has proved advantageous to have only a few standard types, and it is usual to ha each type from one manufacturer only. This is particularly advantageous in a property that is as far-flung as that of the Inspiration Consolidated Coppe Co.

Steel for drilling has been standardized for each type of machine. attempt was made to make standard a steel with a 1-inch hollow round sectio for all machine work. This section seemed too light for drift work, as breakage was excessive, and, on the other hand, it was rather heavy for raise work. At the present time 7/8-inch hollow hexagon and 7/8-inch quarter octagon stee are used with pluggers. Seven-eighths-inch quarter octagon hollow is used with stopers, and 1-1/4 inch hollow round with Leyners. The steel has usuall been furnished by American manufacturers, though recently a good deal of Swedish steel has been tried out.

All the steel is sharpened by air-operated sharpeners. The bits are the usual double-taper type, with two cutting edges crossing at right angles. In an average month 22,000 pieces of steel are sharpened. This is .036 pieces per ton of ore produced.

Blasting. - The quantity of powder used per hole and per round is regulated in part by the shift bosses and foremen in charge of the work where the powder is to be used. No doubt if any error is made, it is that too much powder is used rather than too little. Less than two-tenths of a pound of powder is used per ton or ore produced.

Powder is purchased in carload lots. Gelatin-type explosives in strengths of 30 and 40 per cent have been used exclusively for a number of years. Two principal magazines are used for powder storage; one serves the Keystone area and the other the Inspiration and Main Live Oak areas. From these magazines the powder is shipped in wooden mine box cars to auxiliary magazines underground, where a 24 hours' supply is maintained.

Fuse is bought by the carload; the unit is a spool on which is wound three thousand feet; this gives fewer ends than would the use of smaller units, and there is some time saved in making up the various lengths for blasting. At the present time the fuse is cut in 7, 5, and 3 foot lengths.

In general, No. 6 strength caps with fuse are used for blasting. Bowlders, however, are blasted by means of electric detonators, which are also sometimes used in stopes and long raises.

Mucking. - The broken material in development headings is usually shoveled by hand into mine cars. Various makes of mechanical shovels for use in extending haulage drifts have been tried out at Inspiration at considerable expense but have not proved successful. The most practical mechanical installation for mucking out drifts has been a scraper drawn up an incline by means of a double-drum air-operated hoist. The cable from the hoist runs through a block anchored in the face. Two cars are pushed under the upper end of the incline and loaded one after the other. The frame is built in the company shops. The installation can be easily taken down and put up in half a shift; sufficient cable is used so that it need be moved only about every 125 feet of drift advance. It is easy to keep in operation; the operation requires only two men; mine labor can operate it efficiently; repair costs are low and first cost is also low. Two men have loaded and hauled to the dump a total of eleven 5-ton cars in a morning's work. On the other hand, the scraper can not be readily moved from heading to heading. If, however, many long headings were being driven, each heading could be equipped with its own scraper at a reasonable cost. The scraper idea was tried out some years ago for cleaning up grizzly drifts and crosscuts; but while the faces could be cleaned up more quickly after the scraper was ready for work, the getting ready and moving from one face to another quite destroyed the efficiency of the apparatus. The grizzly drifts have a maximum raise interval of 25 feet, so that these are easily cleaned out by one man shoveling to the raise opening behind him. In crosscuts and in slice drifts where muck has to be moved further than easy shoveling distance, wheelbarrows are used for transporting the broken material. In some instances an 18-gage track with car equipment has been used, but up to 100 feet a wheelbarrow furnishes the most efficient transport. Recently, a scraper has been used successfully in slice drifting where there were two faces that could be cleaned from the same set-up.

Cycles of Operation

Drifts. - Rounds in haulage drifts are drilled with mounted or unmounted machines, depending upon the ground. The number of holes drilled varies from six to fifteen; the depth of the round is sufficient to advance the drift enough for a 5-foot set. Nearly all drifts have to be timbered. After the completion of the drilling the equipment for this work is taken back out of range of the blast, and the holes are loaded and shot. This work takes the major part of a shift, so that blasting is done at the end of the shift. At the beginning of the following shift a timberman is sent in to make safe the back and sides of the drift. The muckers at the same time start work a considerable distance back in the drift by clearing up the broken rock thrown back by the blast. Mucking is pushed so that permanent timbers can be placed in the drift during this shift. Sometimes, however, timbering is done on the drilling shift after the round is completed. The contractors may vary the procedure at times by drilling the upper part of the round and mucking on one shift, finishing mucking and drilling, doing the timbering, and blasting on the following shift.

In small timbered drifts the cycle is the same, and in small untimbered drifts the only variation is in the absence of timbermen.

Raises. - In raises where timbering is necessary the cycle is the same as in drifts, except that there is no mucking to do; quite often the breaking of the ground and the timbering are done by the same man; moreover, as these rounds can usually be put in in a relatively short time, it is possible that a number of rounds may be drilled and blasted during a shift. Usually a round is drilled in the first part of the shift and blasted at mid-shift time, and another drilled and blasted at the end of the shift. However, in a mine works on a three-shift basis this is not strictly adhered to. If the ventilation is good and it can be done with safety, rounds are sometimes blasted as soon as they are drilled and loaded, regardless of the time.

Mining

The stoping of the ore bodies of the Inspiration Consolidated Copper Co. has been going on for the past 14 years, and from the beginning of operations the "caving system" has been used.

At the start of mining operations there was some doubt as to the feasibility of caving a 200 to 300 foot back of ore. The first mining was done with about 75-foot backs, and the ore was run through raises to the haulage level; but as this height was successfully drawn, the next step was to take all the thickness at one operation. This very materially cut the development costs per ton of ore.

The low height of backs at the start made a secondary haulage level necessary, but as mining proceeded, most of this level was abandoned as a haulageway.

"Square-Set" Caving Method. - From the start of operations a standard system of development was carried out. The first area to be mined was the Inspiration division ore body, and in this the so-called "square-set" caving method was first used on a large and systematic scale. (See figs. 5 and 6). Haulage drifts were driven on lateral intervals of 100 feet; along these drifts at intervals of 25 feet pony sets and loading chutes were put in over the drift sets (see Figs. 7 and 8). From these pony sets raises were driven in planes at right angles to the haulage drifts. The slope of these main raises varied from the vertical to a minimum of 43°; a slope of 43°, however, proved too flat for the ore to run well. In general, the raises driven in the early development

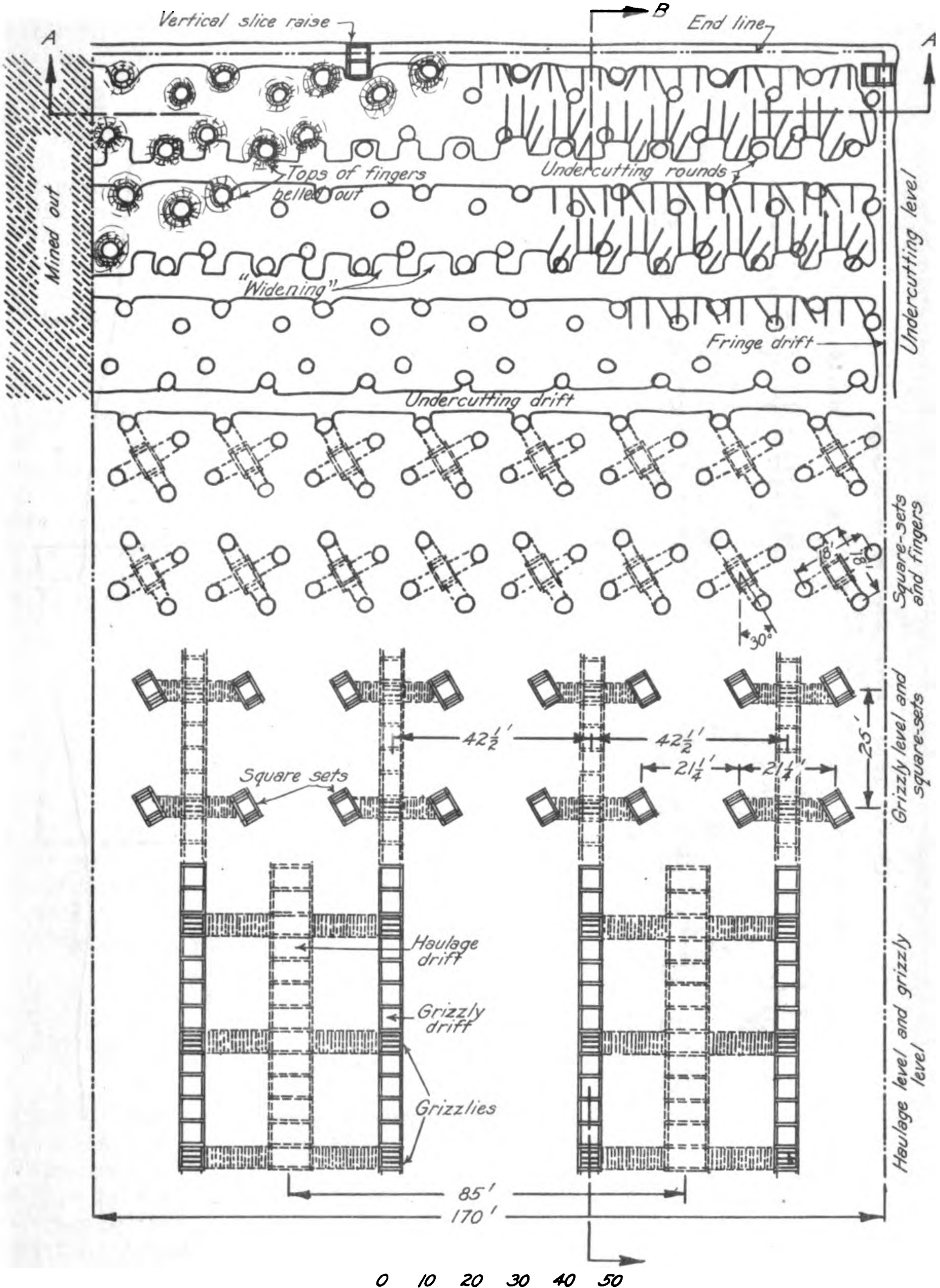


Figure 5.- Plan of "square-set" caving method

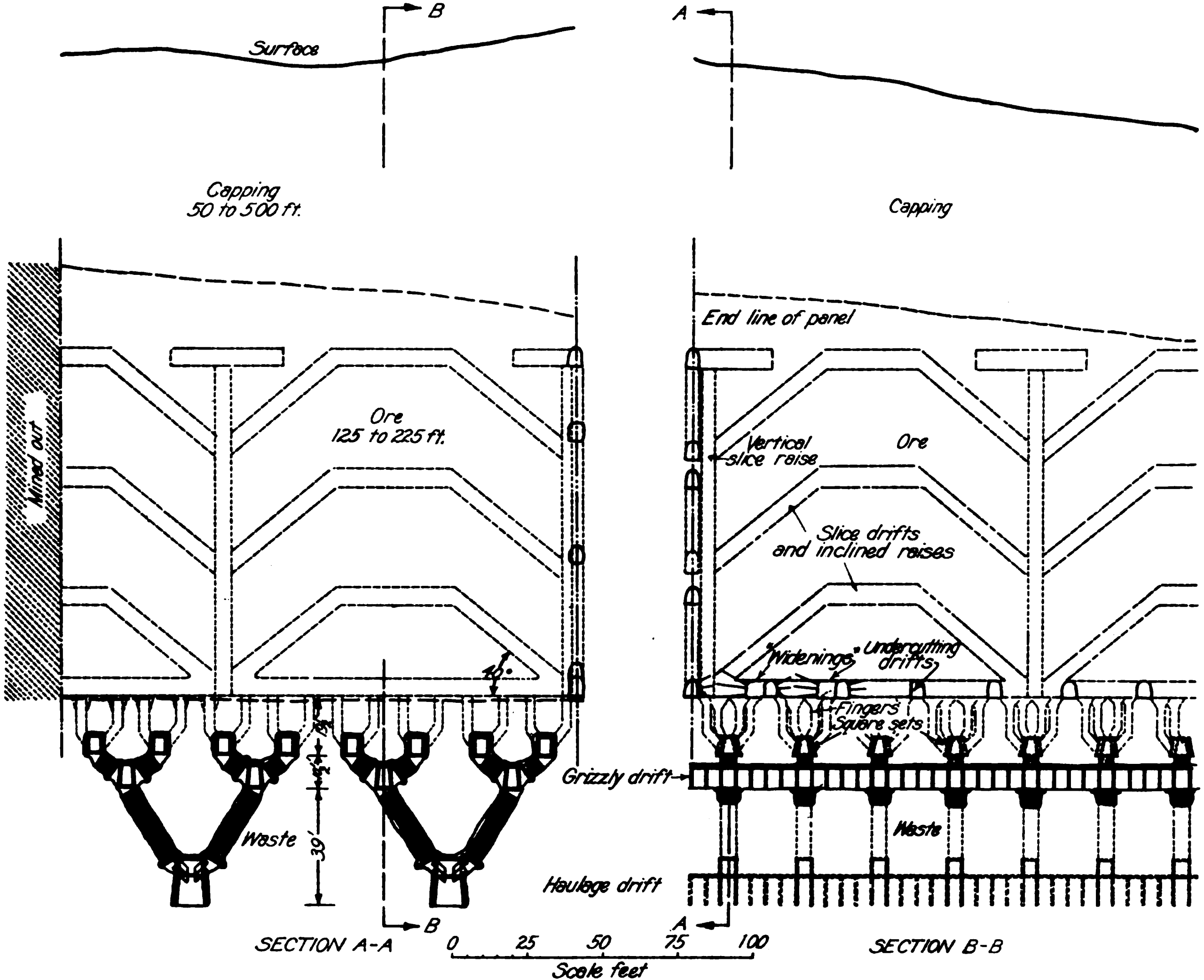


Figure 6.- Sections showing "square-set" caving method

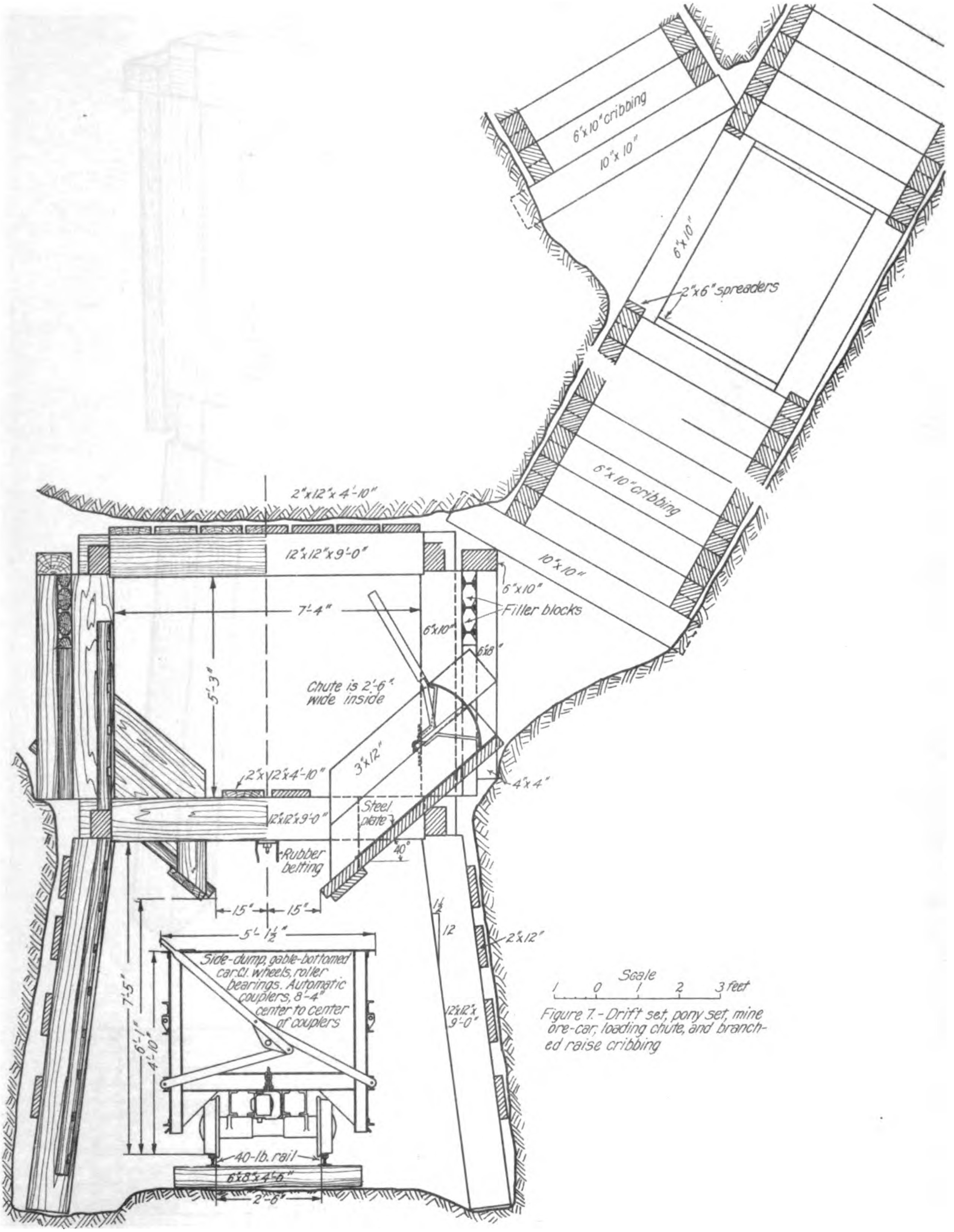
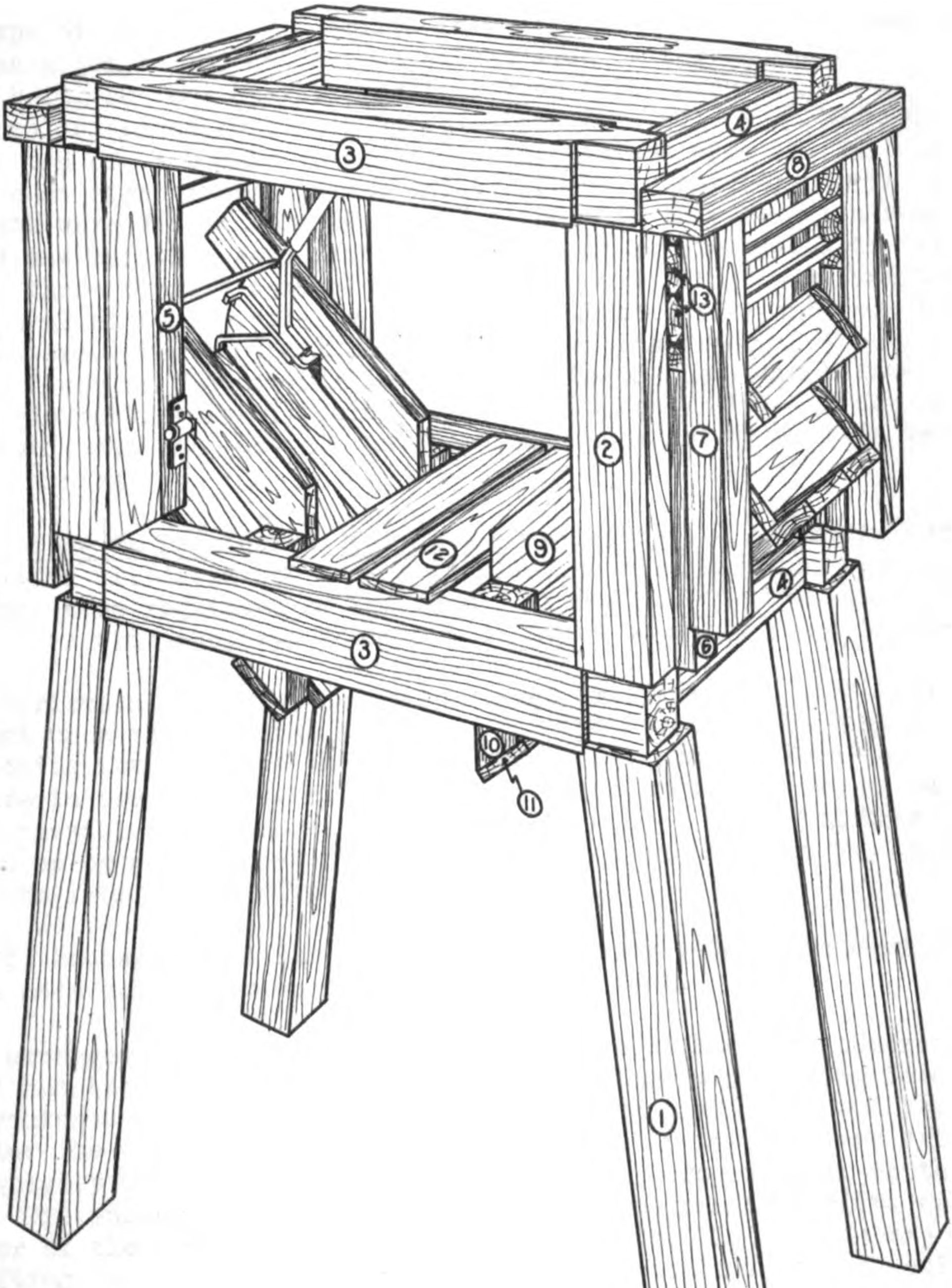


Figure 7.- Drift set, pony set, mine ore-car, loading chute, and branched raise cribbing



Mark	Name	Number required	Dimensions	Remarks
1	Posts	4	12"x12"x 9'-0"	Top cut to 1½ : 12 batter
2	Posts	4	12"x12"x 5'-4"	
3	Caps	4	12"x12"x 9'-0"	
4	Collar braces	4	6"x 8"x 4'-2"	
5	Fillers	4	6"x10"x 5'-4"	
6		4	4"x 6"x 5'-4"	
7		4	6"x 8"x —	Length to fit ground
8	Caps	2	6"x10"x 6'-0"	
9	Chute sides & bottom	14	3"x12"x —	
10	Fillers	4	6"x 8"x —	
11		2	2"x12"x 4'-0"	
12	Platform	2.	2"x12"x 4'-10"	
13	Filler blocks	12	4"x 6"x 6"	Shaped to fit rails

Figure 8. - Perspective view of drift and pony sets and loading chutes

were on a slope of 50°. Grizzly drifts intersecting the tops of these raises were driven parallel to and 25 feet on either side of the center of the haulage drifts, thus being 50 feet apart; grizzlies were built over the top of each raise, using rails spaced 10 inches apart. (See fig. 9.) From the grizzly drifts at the top of each main raise two further raises were driven, one in each direction at right angles to the drift. These raises for the first 18 feet of their length were driven on a 40 to 42° slope. At this height a square-set (see fig. 10) was built in each raise from which four more raises or "fingers" were driven. These fingers connected with the undercutting level drifts which were driven parallel to the grizzly and haulage level drifts and were spaced on 25-foot centers. The vertical interval between the floor of the haulage level and the floor of the grizzly level was 30 to 35 feet, and between the grizzly and undercutting level the interval was 30 feet. This arrangement of drifts was sound, and, in general, has remained unchanged where this system has been used for mining.

Variations in Development for square-set System. - Intervals between haulage levels in all divisions of the Inspiration mine have not been uniform but rather have been regulated by the necessity for fitting the mining to the bottom of the ore with the best economy that could be anticipated in advance.

The horizontal interval between haulage drifts in the mining area is also dependent upon the vertical distance from the level to the bottom of the ore. In reaching for high ore the drifts may be far apart. When the drifts themselves are in ore it is usually desirable to undercut the ore at as low an elevation as possible; therefore, the drifts are spaced close together. This can be summed up by saying that the horizontal interval between the haulage drifts has been from 20 to 200 feet.

On the haulage level the spacing of the "pony sets" necessary for starting the main raises has varied from 75 to 15 feet.

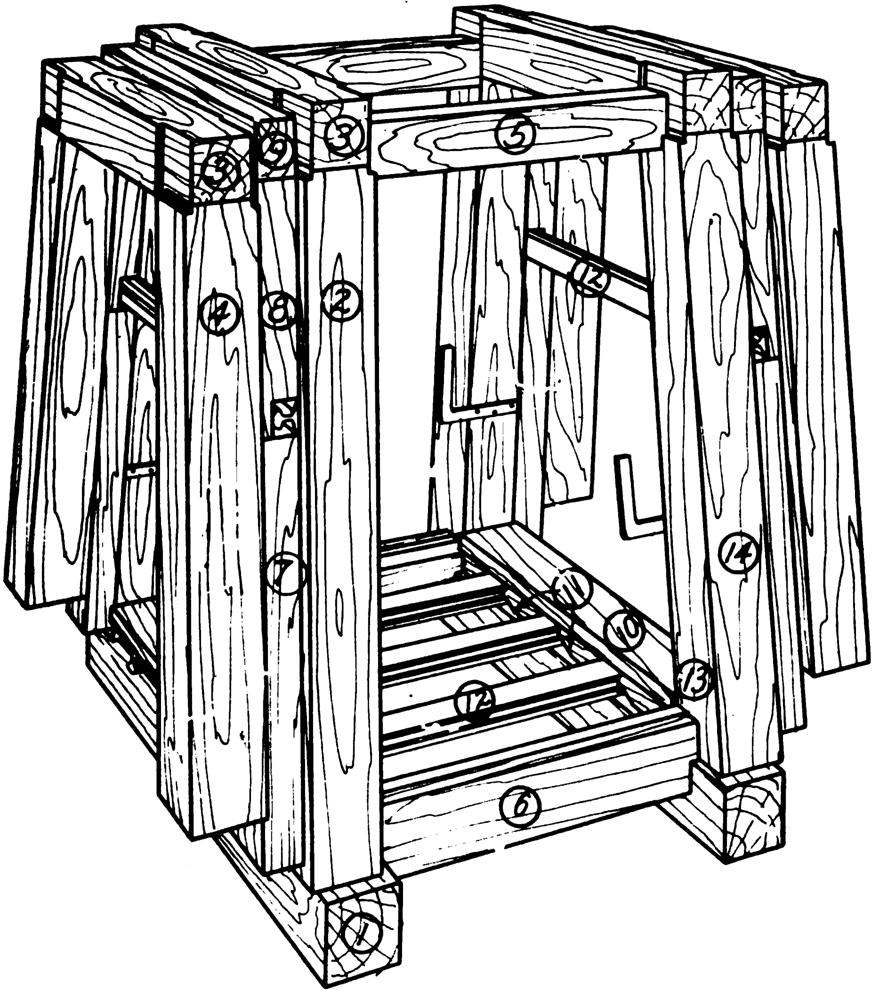
The arrangement of drifts on the grizzly level has seen numerous changes. It has been the habit at Inspiration to take a promising idea, discuss its advantages and disadvantages, and if apparently a move was being made for the better the new idea was tried out. Originally with haulage drifts 100 feet apart grizzly drifts were spaced on 50-foot centers parallel to the haulage drifts. The apices of the raise systems from the haulage drifts were then in the center of the space between the haulage drifts. Later a scheme of grizzly drifting on 33-1/3-foot centers, but still parallel to the haulage drifting, was tired out with very indifferent success. As the interval between the haulage drifts was decreased the interval between the grizzly drifts was decreased from 50 to 42.5 feet. Due to changes in the raise systems the interval at times has been reduced to 25 and even to 20 feet.

There has also been much variation in the area tributary to a draw hole. Perhaps actually as well as theoretically the area affected by each draw hole should be as small as possible in order to give the best control of drawing, although this is perhaps truer with ore that breaks into small fragments than with ore that is coarser and hard after being broken. The arrangement of the branch raising and the square-sets has been the cause of endless experimenting, which is not ended yet. It can be understood that each square-set with four fingers should draw the ore from 625 square feet, and the desired result is that the fingers should be spaced so that each finger will have 156.25 square feet - no more, no less. It is not particularly difficult to outline such arrangements on paper, but very difficult to put them into practice. Figures 11a and 11b show some of the efforts made to equalize the areas of drawing raises. Efforts were made in the early days of the application of the square set system to increase the number of draw points from four to six, and even eight, but neither was found to be practicable.

The "Grizzly-Control" Caving Method. - Many millions of tons of ore were produced by the square-set caving system at Inspiration, and it continu to be a standard system of mining, more particularly where ground conditions are favorable. In some respects it is not an ideal system; one important disadvantage is that men have to go above the level into the square-set to draw the ore. This makes supervision of drawing difficult. The square-set itself is not easy to inspect or to repair. The best place for drawing ore is at th grizzly on the grizzly level; inspection of ore being drawn is then easy, the condition of the drawing area is readily seen, and above all, maintenance is greatly facilitated. Although these conditions were realized from the start of operations, there was no necessity for change until mining was begun in the Live Oak division. Ground conditions in this division were entirely differen from those at Inspiration. The square-set system was tried, but with very indifferent success. The ground in the Live Oak division when caved broke into small pieces, and these pieces packed together readily; the result of thi condition was that when the ore was drawn, "piping" occurred. These pipes we small in section and seemed to go up vertically. This meant that many areas were imperfectly drawn. The necessity of a closer interval for raising was definitely shown. To arrive at this closer draw interval the raises were spaced at 12-1/2 feet along the grizzly drift; the raises were put up at rig angles to the drift, and the usual square-sets put in--though with this diffe ence, that from one set the usual four raises were driven and from the next s only two. Still the grizzly drifts were 50 feet apart, and the draw was controlled by square-sets. It was then found that good drawing could be done fr the grizzly level in this method, but the space between grizzly drifts was to wide; the interior area could not be reached. The next step was to put the grizzly drifts closer together, 25 feet apart, and space the grizzlies 12-1/2 feet apart. In soft ground a number of draw chutes could be put in at one grizzly, and this materially helped the extraction if regular drawing were practiced. This system has worked out so well that it has become a standard system at Inspiration. The distance apart of grizzly drifts has been standa ized at 25 feet, though they may be either parallel or at right angles to the haulage. The grizzly interval varies from 12-1/2 to 17 feet. The number of draw holes from the grizzly varies from two to ten. If the ground conditions permit the undercutting is done directly from the raises. Figures 12 and 13 illustrate the typical grizzly-control method. Figure 14 is a plan and section showing the inclined-slide caving method, which is also used at Inspiration.

Underground Transportation

Hand-tramming was satisfactory in the early days of underground devel ment while the results of a part of the churn-drilling were being checked. The track gage at first was 18 inches. During the latter part of this period



Mark	Name	Number Required	Dimensions	Remarks
1	Sills	2	10 x 10	Length to fit ground
2	Posts	4	10 x 10 x 7'-0"	Dap 3 sides 1" at top
3	Caps	4	10 x 10 x 5'-4"	" " " "
4	Posts	4	10 x 10 x 6'-0"	" " " "
5	Collar braces	2	6 x 8 x 4'-0"	
6	Spreaders	2	5 x 10 x 4'-2"	
7	Fillers	4	6 x 8	Length to fit ground
8	Fillers	4	6 x 8 x 2'-4"	
9	Caps	2	6 x 8 x 5'-0"	
10	Planks	2	2 x 12 x 5'-0"	
11	Filler blocks	8	4 x 6 x 14"	
12	Rails	5	40 lb. 6'-0" long	
13	Wear iron	2	3 x 3 x 1/4" long	
14	Brackets	4	1/2 x 1-1/2" strap	
15	Lagging	4	2 x 12 x 5'-4"	Not shown in drawing
16	Chute boards	2	2 x 10 x 5'-4"	" " " "
Total board feet = 1043				

Figure 9. - Grizzly-control set.

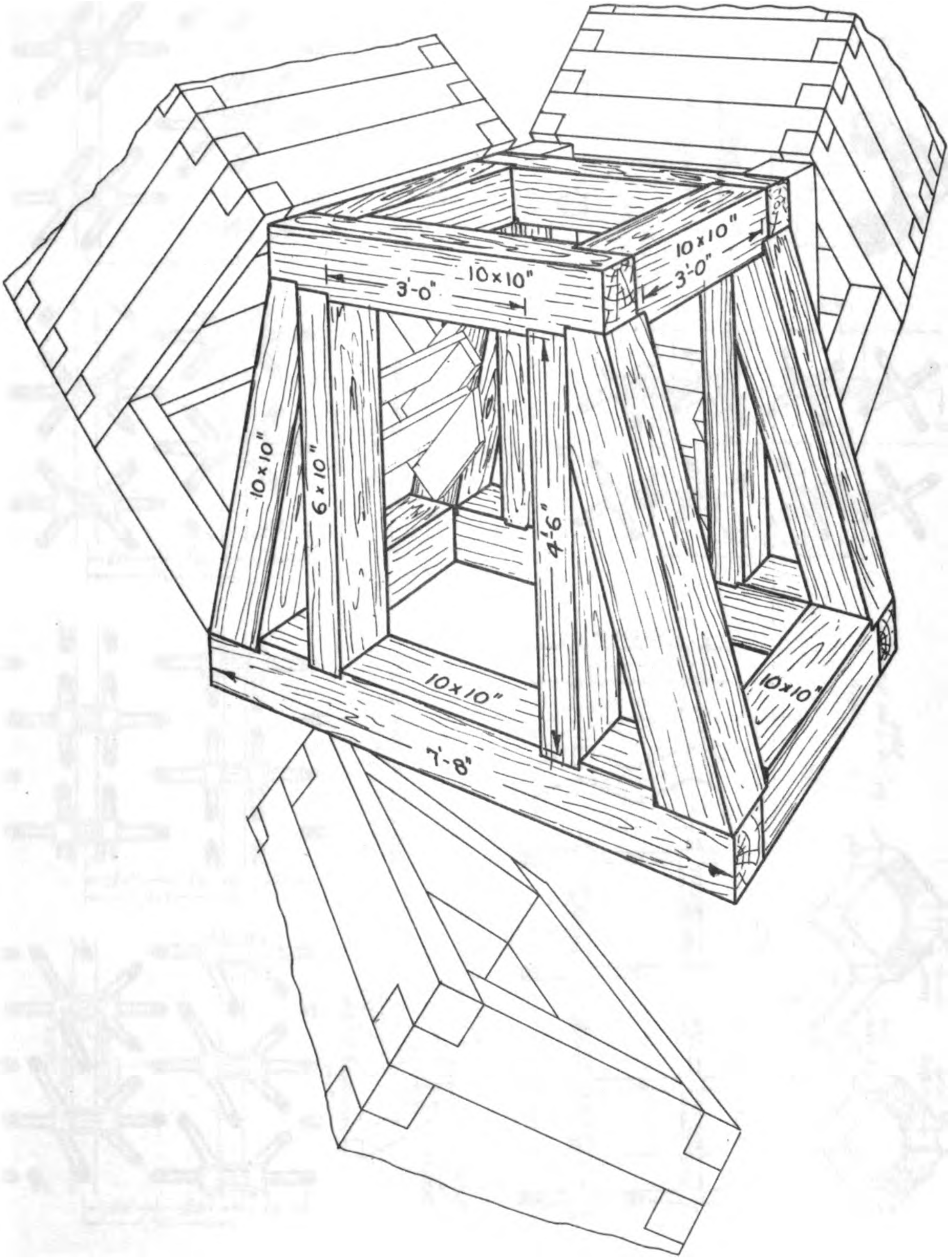
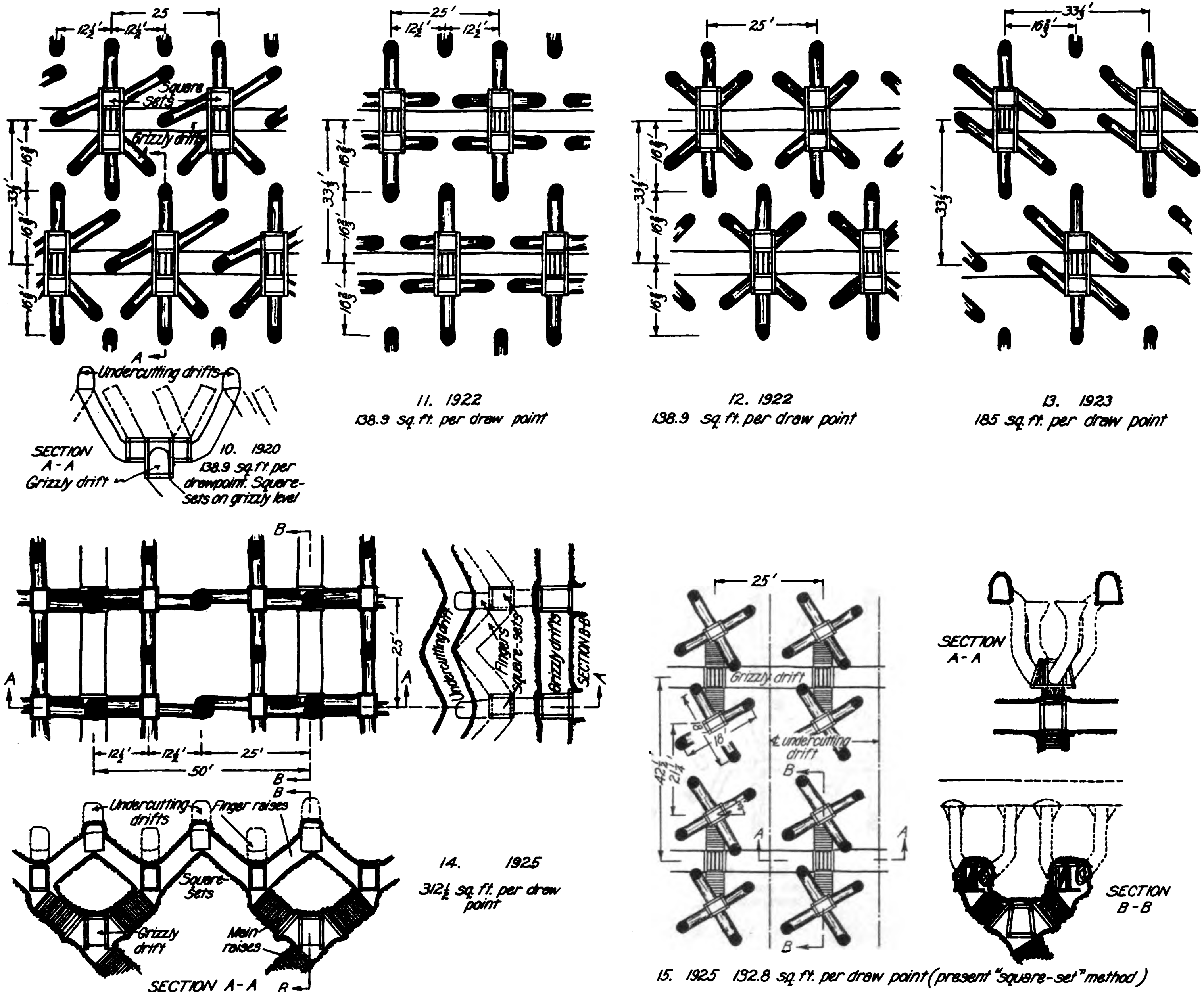


Figure 10. - Square-set for control of drawing in square-set caving method



10. 1920 138.9 sq. ft. per drawpoint. Square-sets on grizzly level

11. 1922 138.9 sq. ft. per draw point

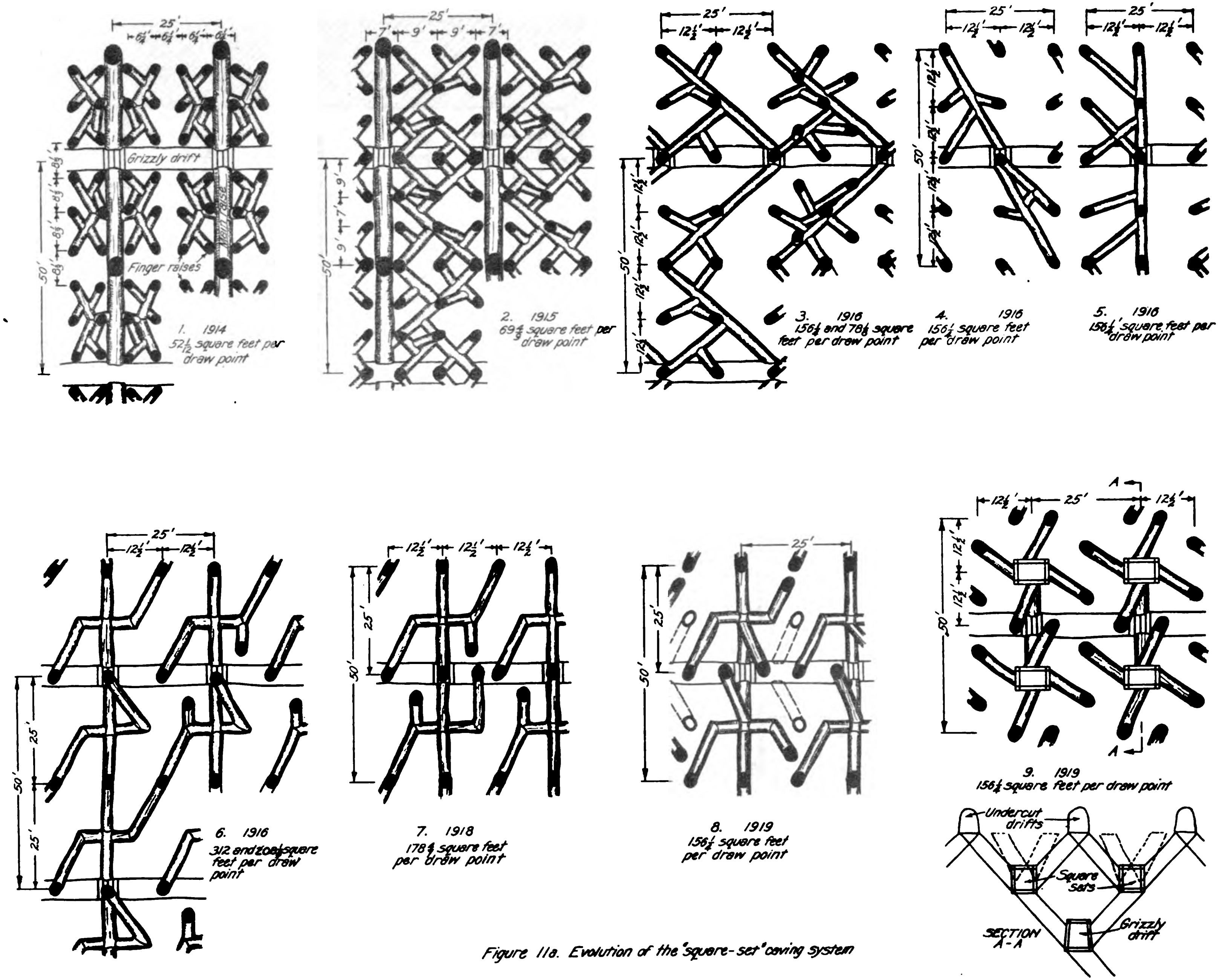
12. 1922 138.9 sq. ft. per draw point

13. 1923 185 sq. ft. per draw point

14. 1925 312½ sq. ft. per draw point

15. 1925 132.8 sq. ft. per draw point (present "square-set" method)

Figure 11.- Evolution of the "square-set" caving method



1. 1914 $52\frac{1}{12}$ square feet per draw point

2. 1915 $69\frac{4}{9}$ square feet per draw point

3. 1916 $156\frac{1}{4}$ and $78\frac{1}{8}$ square feet per draw point

4. 1916 $156\frac{1}{4}$ square feet per draw point

5. 1916 $156\frac{1}{4}$ square feet per draw point

6. 1916 312 and $208\frac{1}{3}$ square feet per draw point

7. 1918 $178\frac{4}{7}$ square feet per draw point

8. 1919 $156\frac{1}{4}$ square feet per draw point

9. 1919 $156\frac{1}{4}$ square feet per draw point

Figure 118. Evolution of the 'square-set' caving system

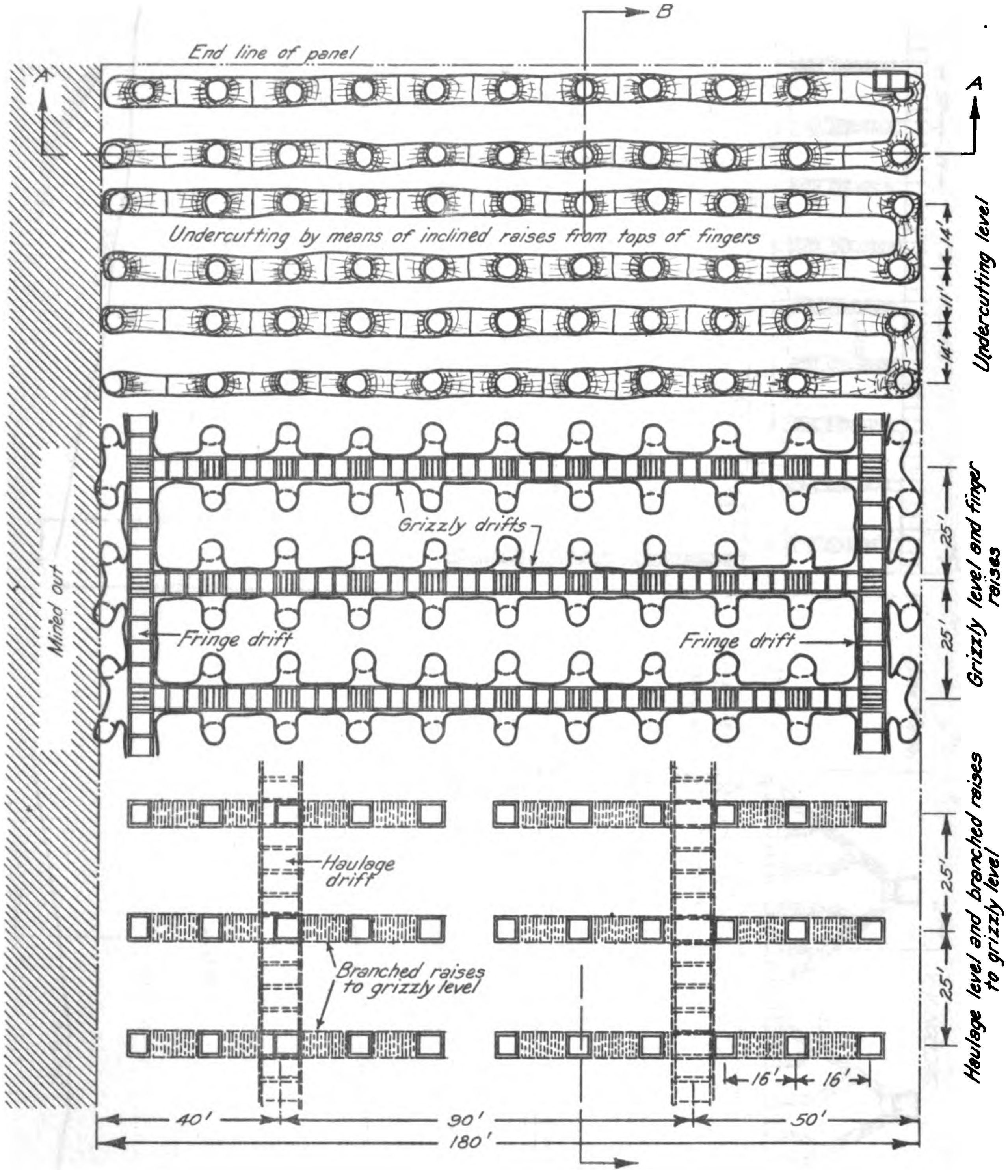

B
End line of panel
A
A
Undercutting by means of inclined raises from tops of fingers
Undercutting level
14'
11'
14'
Grizzly drifts
Grizzly drifts
Mined out
Fringe drift
Fringe drift
25'
25'
Grizzly level and finger raises
Haulage drift
Branched raises to grizzly level
25'
25'
Haulage level and branched raises to grizzly level
16'
16'
40'
90'
50'
180'
0
25
50
75
100
Scale feet

Figure 12.- Plan of "grizzly- control" caving method

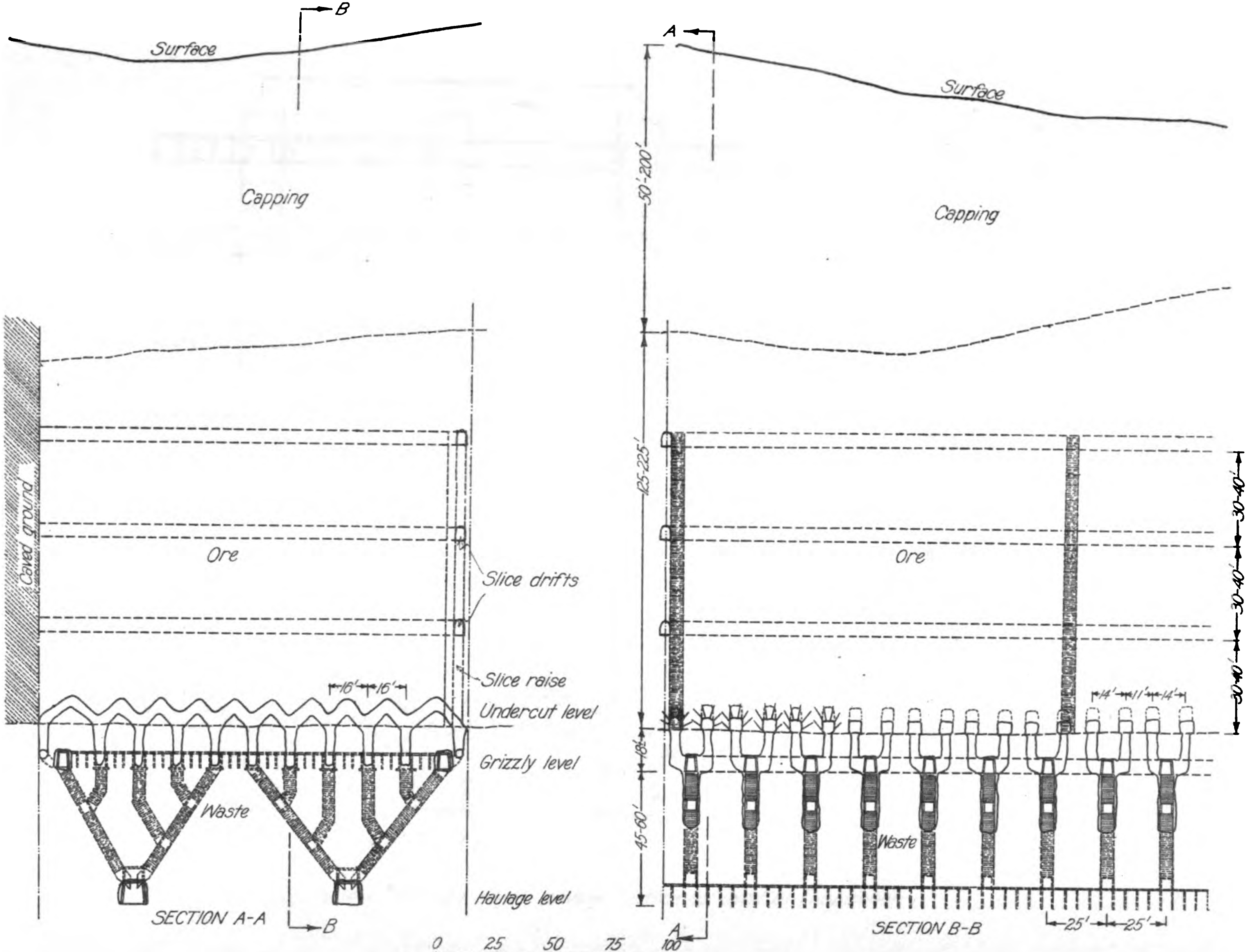


Figure 13.- Sections showing "grizzly-control" caving method

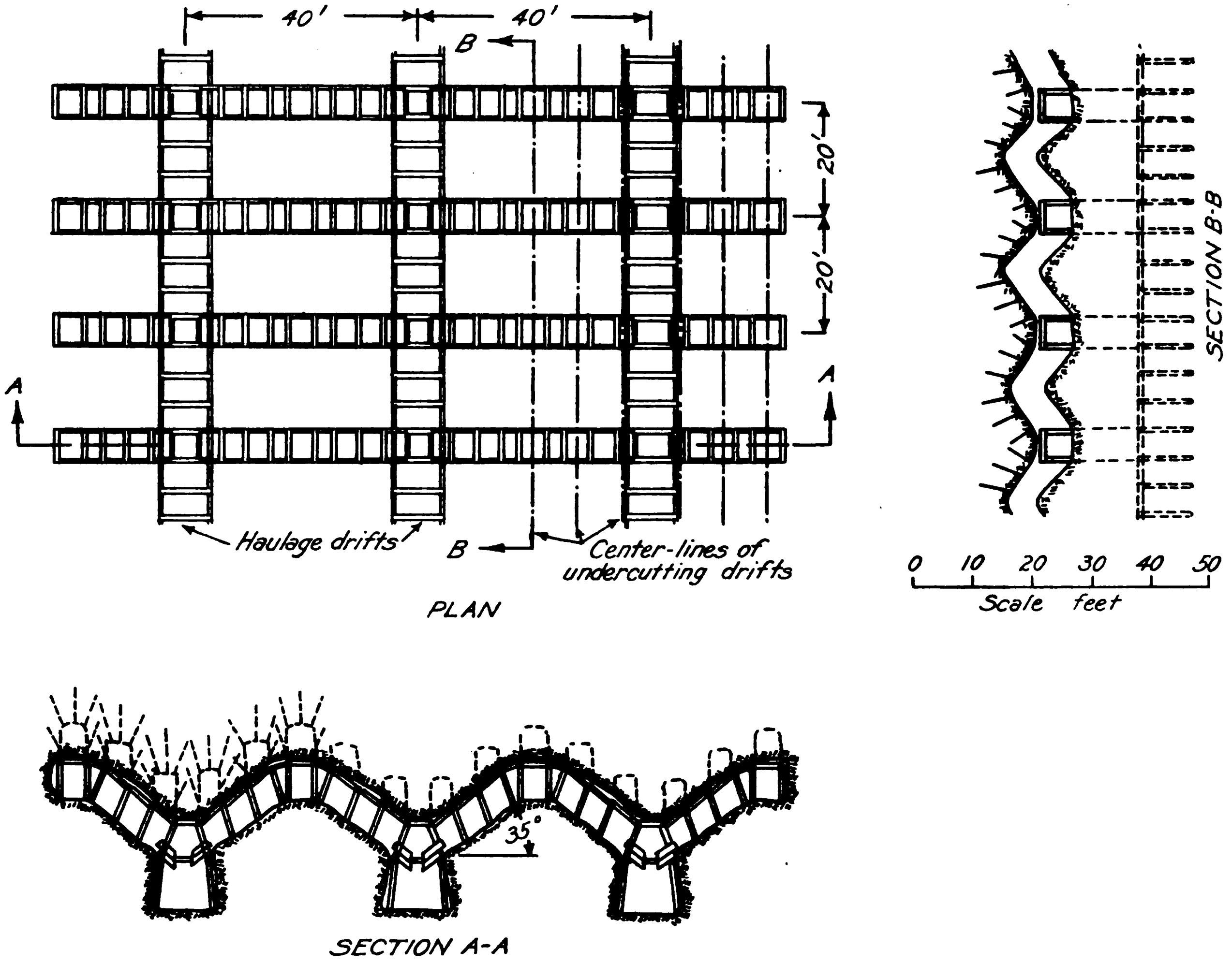


Figure 14.- "Inclined slide" caving method as used at Inspiration

a development and supply adit having the cross section intended for future haulage drifts was driven in from Live Oak Gulch. For a considerable distance the track in this adit was laid with a 36-inch gage, and trolley locomotive haulage was installed. It was soon apparent, however, that a 36-inch gage track in a drift of this size did not allow enough clearance. The gage then was changed to 30 inches, which became the standard for the mine. About the time that this change was made the driving of main haulage drifts on other levels of the mine was started from the development shafts; the track gage in this new work was 30 inches and the motive power either a horse or a mule. Animal haulage was adequate as the hauls were not long, nor the daily tonnages large. However, before this development work was finished the amount of material to be moved had greatly increased and electric trolley locomotives were installed. These served during the remainder of the development period.

Locomotives. - Although the efficiency and economy of electric haulage were recognized, the question of its safety was considered debatable, especially under the intensive loading of cars and movement of trains that the company anticipated. For considerable distances haulage was to be through drifts in which loading chutes were spaced at 25-foot intervals on both sides of the drift. The guarding of the trolley wire at the chutes and the protection of men while loading cars was considered such a serious problem that it was decided to adopt a haulage system in which the hazard of the trolley wires was eliminated. Compressed-air locomotives which were in use at several surface plants were investigated and found to be successful and safe. This type of motive power was then adopted for the Inspiration mine and used exclusively until 1926.

The air locomotives are of the cross-compound type; air enters the high-pressure cylinder at 250 pounds through a reducing valve and exhausts through a cellular heater into the low-pressure cylinder at 125 pounds per square inch. The capacity of the storage tank is 105 cubic feet; it is charged from the air line at 850 pounds pressure. The length of time necessary for charging varies from 30 seconds to a minute.

In discussing this type of haulage it can be said, of course, that whatever danger existed from the trolley wires was eliminated, but dangers and difficulties not at first thought of were introduced. A reciprocating machine is not so easily controlled as a rotating machine; therefore, air locomotives require more careful handling than electric motors. This is particularly noticeable when the air motor has a heavy load that is difficult to start. Often when given a full head of air there is a decided jump upon starting which is dangerous. The couplings at the charging stations break at times and allow the swiveled connections to fly about with terrific force. Finally, the speed of the trains can not be controlled so easily as with an electric motor, and excessive speed is particularly dangerous under mine conditions.

An air locomotive has one advantage that might be overlooked - it can still pull cars through drifts in heavy ground where clearance has been considerably reduced, while with trolley locomotives allowance must be made for the trolley wire. Of course, it may be said that a storage-battery locomotive has the good points and none of the failings of an air motor. This can now be granted, but the storage-battery locomotive was in its infancy when Inspiration adopted the air motor.

In 1926, upon the beginning of development operations in the Sulphide Tunnel division of the Live Oak and with the necessity for moving large tonnages of ore to the Inspiration main shaft, a distance of 1-1.4 miles, carefu study showed that air motors would not be economical for this service. Too much time would be lost in charging the motors, their starting effort was insufficient, and a sustained moderate speed was considered more advantageous than the high speed to be obtained by the air motors between charging stops. For these reasons 8-ton, two-motored electric trolley locomotives were put in this service. Trolley locomotives of the same size were also installed in other portions of the mine where haulage conditions were favorable, and have proved satisfactory.

Cars. - During the hand-tramming period of the early development days end-dump, 14 to 20 cubic foot cars were used. When animal and the first electric haulage were adopted, the same cars were used in extending haulage drift As the tonnage movement increase , rocker-dump cars of 2-ton capacity and side-dump cars of 1-1/2-ton capacity were placed in service. The rocker-du cars are still used in development work and have proved to be a convenient t

Previous to placing the mine on a production basis the standard type of car for haulage was decided upon. Its construction was all steel, its cap ty 102 cubic feet or 5 tons, and its length, center to center of couplers, wa 8 feet 4 inches. The car was a simple box mounted without springs on four wheels. Crown brass bearings were used. This type of car has hauled the ma portion of Inspiration production.

As the mining areas were extended to the Live Oak division and more haulage levels were opened, the question came up for decision as to whether or not these new levels should be equipped with the box-type cars. It was decided to change to a roller-bearing side-dump car of nearly 5-ton capacity an of the same length as the box-type car. These cars have been found satisfactory in most respects. Although the original tipple-dump cars were all fitte with crown brasses, a change is being made to tapered roller bearings. Even cars that at first were equipped with cylindrical roller bearings are now being fitted with tapered bearings. All types of cars in use have about the same capacity, varying only from 98 to 102 cubic feet.

The advantage of a side-dumping car is that it discharges its load without mechanical help. The disadvantage is that leakage around the doors is very difficult to prevent and the constant clean-up of drifts is costly. Moreover, the additional moving parts cause some trouble.

A box-type car must be dumped by some mechanical device; at Inspiratio the device is a tipple that rotates through 360°, holds five cars, and is driven by a 35-hp. electric motor through clutch, shaft, and gears. Fortunately for continuous production, the level from which the major portion of the ore comes is equipped with two tipples. This provides a partial outlet for production when one tipple is out of commission for repairs.

The type of tipple in use at Inspiration necessitates the uncouplin of 5-car units for dumping; when dumped these cars are "kicked" off the tippl and five others are placed for dumping. This is hard usage for the cars. A tipple with horns at either end for stopping and holding the cars in position and which rotated 180° back and forth was tried out. It was so designed that the cars were not supposed to be uncoupled in dumping. This machine, however, did not come up to expectations and to get satisfactory dumping capacity it was necessary to discard the device and put in the side-dumping cars.

Track. - From the start of operations the standard weight of rail in use was 40 pounds to the yard. On a long heavy haul it was decided to use 60-pound rails, but this is the only exception to the 40-pound standard. Frogs were at first of ordinary steel construction, but these did not give satisfaction. Under severe conditions it has been necessary to replace them at 24-hour intervals. Solid manganese-steel frogs were used as replacements and have now become standard.

Curves are usually run on a minimum radius of 60 feet, although curvatures as short a radius as 35 feet have at times been necessary on account of local conditions.

Inspiration was among the first metal mines to install a centrally located and electrically operated switch-throwing device. By means of this control, track switches routing trains to either terminal can be thrown. This increases the safety of haulage operations as helpers do not have to leave the car or motor to throw switches; moreover, it materially speeds up train movement through the most congested areas.

To increase further the safety and speed of train movement, an electric block system was installed. This system is the same as that used on steam railroads. In some congested areas caution signals were installed in connection with the block system.

Trains and Car-Loading. - Trains for tipple dumping are made up of 15, 20, or 25 cars. The side-dumping cars are made up into trains of from 10 to 20 cars; the number in this case has no effect upon the efficiency of discharge, as each car is dumped as a unit.

The car length of 8 feet 4 inches from center to center of couplings was determined by the distance between chutes in the haulage drifts. As this distance is 25 feet, every third car of a train can be placed under a chute for loading. The multiple for loading does not always correspond with the dumping multiple; nevertheless, loading can be materially speeded up in this way. The loading of the train consumes the largest percentage of the round-trip time and is the point where the most time can be saved.

In each important loading drift there is at least one "raise-runner" whose work it is to keep the chutes clear of bowlders and timber. If chutes are in good condition this man helps with the train loading.

The train crew consists of three men - a motorman and a helper at the front end of the train, and another helper at the rear end. When loading, both helpers "run" chutes, the motorman moving the train as required. When dumping at the tipples, one helper is stationed at one end of the tipple to uncouple the cars and one is placed at the other end of the tipple to signal to the tipple operator that the cars which have been dumped are in the clear and the cars on the tipple are in position for dumping. The end of the tipple where uncoupling is done is in view of the tipple operator. In dumping side-dump cars, both helpers are employed.

Transfer Raises. - In the movement of Keystone division ore it is necessary to transfer the ore from the third to the sixth level, a distance of 350 feet, (see fig. 13). The ore is loaded on the third level in side-dump cars and hauled to transfer raises. There are eight transfer locations on the third level where cars may be dumped. At the Live Oak No. 1, two side-dump locations are arranged with a manway raise between. At the sixth level the pocket at the bottom of these two transfer raises is fitted with four air-operated gates for the loading of four cars at the same time. In this transfer there is no intermediate control.

The Keystone No. 1 and No. 2 are vertical transfer ore passes with one control between the third and sixth levels. There are two dump locations on the third level tributary to No. 2 ore pass. On the sixth level four air-operated gates and air-operated hoppers are used for car-loading at each pocket. These two ore passes are 50 feet apart, and in the space between is a vertical two-compartment raise. In one compartment is a cage which travels from the third to the sixth level. The other compartment is used for a ladderway. At 25-foot intervals this raise communicates with both ore passes.

The Keystone No. 3 has three dump locations on the third level. On the sixth level air-operated gates are used to load two cars at a time. A separate manway raise is connected with this transfer raise at 60-foot intervals to a height of 200 feet. At this height the raise is branched, as shown, to connect with three haulage drifts on the third level, and control chutes are installed in each branch. At this elevation also a drift connects the No. 3 Keystone with the Nos. 1 and 2.

This arrangement of ore passes with controls allows the separation of sulphide and oxide ores in the same raise and permits maintenance work to be done in part of a raise while the other part is in use. The number of separate transfer raises provides against interruption of ore movement.

Pockets. - At the Inspiration main shafts the original installation was designed for hoisting from one level. There were two haulage levels, but the upper level pocket was not arranged for hoisting; instead, as shown in Figure 4, it was connected by a transfer raise, branched at the lower end, with the two pockets on the lower level. The flow of ore is controlled by a hand-operated gate at the bottom of each branch. The upper pocket and transfer raise have a storage capacity of approximately 1,600 tons.

In the floor of each pocket are two openings which allow ore to flow onto the feeders in the loading-floor room. In this room are four drum-type motor-driven feeders. Each feeder discharges into a hopper which can hold one skip load and is so counterbalanced that when filled the feed mechanism is stopped. The hopper gate is connected by means of toggles and rods to a tripper in the shaft. When the descending skip hits this tripper, the hopper gate drops open emptying the hopper load into the skip. The hopper gate, being counterbalanced, closes, and the cycle is completed by the automatic starting of the feeder.

At the Live Oak main shaft the loading stations on the tenth and twelfth levels are similar to those in the Inspiration main shafts. Different types of feeders are in use and hoppers are slightly different, but the general idea is the same.

The loading stations on the sixth and eighth levels of the Live Oak main shaft are simpler in construction and operation. Ore runs from the main pocket through an air-operated door into a measuring pocket. This is designed to hold just one skip load of ore, and is closed at the bottom by a second air door. The opening of the lower door allows the measured amount of ore to slide into the skip; the door is then closed, and the pocket refilled. This arrangement has worked out successfully and the cost of installation was considerably less than for the loading devices on the tenth and twelfth levels. The sixth and eighth level pockets have less storage capacity, but it is sufficient. Excess pocket capacity is a safety factor in an underground transportation system, as trains are not delayed on account of lack of dumping space; the same effect is also attained by means of skip-loading arrangements that always permit efficient hoisting from the various levels of a shaft.

Hoisting Equipment. - Ore is hoisted at the Inspiration main shafts by two double-drum electric hoists. The drums are 10 feet in diameter and grooved for 1-3/4-inch rope; one drum is fixed on the shaft and the other has a clutch. The hoisting speed is 750 feet per minute. All hoisting is done in balance. The hoists can be operated by hand from platforms in the hoist room. They can also be operated by remote control by the attendant on the loading floor at the 600 or the 800 level, or both hoists can be set to operate automatically from the upper hoisting level. The lower hoisting level is reached by only one shaft. When it is necessary to hoist from both levels at the same time an attendant on each floor starts the hoist by remote control. The hoist stops automatically when the skip reaches the dumping position.

Under automatic control the two hoists combined can hoist 75 skip loads, or 950 tons per hour; with manual control from the loading floor their capacity is 105 skips per hour.

The Live Oak main shaft is equipped with a double-drum electric hoist. The drums are 12 feet in diameter and are grooved for 1-7/8-inch rope. Hoisting can be controlled either from the hoist platform or from the skip-loading room.

On account of the length of travel, the loss of hoisting time caused by changing from one level to another, and the large tonnage to be hoisted, the hoisting speed at this shaft was originally 2,200 feet per minute. With more efficient operation of the hoist it has been practicable to reduce the speed to 1,500 feet per minute. Although this has lengthened the hoisting period, the ore can ordinarily be removed from the pockets fast enough not to interfere with haulage operations. If hoisting is delayed and the necessity for speed is apparent, the hoist can be run at the higher rate.

The four hoisting compartments at the Inspiration and the two at the Live Oak shafts are all of the same size. Skips are interchangeable if needed. Usually, however, a skip taken from a shaft for repairs is sent back to the shaft from which it came. This is in part due to the necessity for putting "wearing shoes" on the Live Oak main shaft skips. In this shaft the high speed of the skip and the small clearance between it and the front and back walls of the shaft caused excessive wear of the skip surface. This has been remedie by putting on steel shoes made of discarded roll shells to take the wear.

The skips will hold between 13 and 14 tons of ore, but the load is kept as nearly as possible at 12-1/2 tons. This prevents some spilling of ore in loading and in dumping.

At the Inspiration main shafts no provision was made for hoisting wast At the Live Oak main shaft in the original installation, waste from undergrou operations was hoisted by the ore skips. A slide could be lowered into such position that waste dumped from the skips would be diverted into a waste bin. Due to the difficulty of raising and lowering this slide, its use has been abandoned. Waste is now handled in standard mine cars and hoisted on the man cage to a track which runs over the top of the waste bin. Fortunately in the production of a large tonnage of low-grade ore the absolute separation of a relatively small quantity of material too low-grade to be called ore is not of paramount importance.

Supplies. - At the Inspiration division an inclined shaft is used for the lowering of supplies into the mine. A drawbridge connects the incline with the third level of the mine. This level is connected with the surface by an adit which starts from the "tunnel yard." The latter comprises within its limits the mine warehouse, the mine timber framing plant and sawmill, the tool-sharpening shops, and mine machine shop. The explosive supplies for par of the mine are also stored within the limits of the yard.

All supplies are loaded on trucks or into cars in the yard, taken through the tunnel to the inclined shaft and lowered to the sixth or eighth level of the mine. The sixth level connects with the Inspiration and Live Oak main shafts. Supplies for the lower levels of the Live Oak shaft are hauled from the inclined shaft to the Live Oak main shaft and there lowered on the man cage to the lower levels. Generally supplies from the tunnel yard are not unloaded from the trucks until they reach a point on a haulage level near the place of use.

An additional timber yard is maintained at the Live Oak main shaft for both framed and unframed timber. This material is loaded on trucks and lowere into the mine on the man cage.

PERCENTAGE EXTRACTED, ORE AND METAL

The percentage extracted by a caving system of mining is difficult to estimate. It is first necessary to arrive at some basis by which the extraction is to be measured. If the ore reserves are calculated on 1.5 per cent ore and the ore body is overlaid or underlaid with 0.7 per cent material, an apparent 110 per cent extraction of the ore and 100 per cent recovery of the metal of the original calculated block is easy to obtain. However, if the 0.7 per cent taken in consideration in the original estimate or if the dilution is barren capping, such a remarkable recovery can not be obtained.

At Inspiration ore reserves are figured to contain material down to a point where the margin of profit of mining ceases; this is a more conservative basis than many companies use. It is probable that this method increases care in drawing, which results in good ore and metal recoveries. Also, it conserves within reason the ore reserves which are the capital of a mining enterprise. In a given area of development a maximum of ore and metal must be extracted in a minimum time. When the ore drawn from the stopes has paid for the cost of development of the area any additional production has only to meet the mining and treatment costs, and as long as it does so, profitable extraction may continue.

Under the conditions outlined above of ore estimation and drawing at Inspiration a minimum efficiency of 75 per cent is figured. The recovery of the estimated tonnage is in excess of 110 per cent, with a recovery of over 85 per cent of the metal content.

It should be remembered in this connection that at Inspiration no correction is made of the estimate of the grade and tonnage of ore in place. The estimate is made from the results of the churn-drilling done years ago. The only exception is that in certain areas diamond-drilling has been done in recent years to prove the results of the old churn-drilling; although the diamond-drilling usually checks the churn-drilling to a remarkable degree, the former is used in estimating the tonnage and assay of a block for the reason that the assays in this drilling were run carefully for the acid soluble and acid insoluble copper content of the ore. This division of tonnage is of importance where two separate classes of ore are mined for different types of plants--that is, concentrating and leaching.

To a very large extent all development is done in material that carries enough copper to pay treatment charges. Inasmuch as this material has to be mined, it is economy to put it through the treatment plants. This, of course, is true only if there is sufficient plant capacity so that more profitable ore is not crowded out.

The waste disposed of separately from the ore has from the start of production (July 1, 1915) to date (Jan. 1, 1929) amounted to 1.974 per cent; 1,224,984 tons of waste and 60,839,211 tons of ore have been handled.

COMPARISON OF DIFFERENT METHODS USED IN DISTRICT

At present there are but two properties operating in the Miami mining district, and both properties are using the caving system of mining. There are minor differences in the application of the method. These differences are in a large part due to the physical difference in the ore bodies being mined.

WAGE, CONTRACT, AND BONUS SYSTEMS EMPLOYED

Since the start of operations at Inspiration there has always been an opportunity for energetic skilled workmen to earn more than the standard rate of pay for a day's work.

From the start, also, this increment of pay has been based upon a contract system rather than upon a bonus system.

All development work can be contracted in small units to men who have the desire to increase their daily earnings by increased effort or the more intelligent application of their skill. Contracts in small units are desirable from the viewpoint of the company, but more particularly from the viewpoi of the employee. If the contract does not prove to be profitable, the man realizes that he does not have to continue the job for a long period. Althou the contractor can not be paid below the standard wage paid in the district f the class of work being done, it has been found that when a contractor tries and falls below the company account rate of pay, and he knows this without bei told, he is apt to fall below the company account man in the quality and quantity of work done. That is where the company suffers if the contract is continued. With a small contract, adjustments of rates of pay can readily be ma The adjustments may be necessary on account of unforeseen ground conditions, or on account of supply and ventilation conditions which may have had to be changed for operating reasons. Each contract stands on its own basis. Usuall it is true that the same class of work in a division is priced the same, but small units readily allow minor adjustments.

However, the great advantage of any contract system over any bonus system is that a contract system is based upon a unit of work done for a specific price. It can be terminated by either the employee or the company, since it involves an understanding by both parties and has to be mutually satisfactory. It should be remembered that the so-called contract system at Inspiration is just an opportunity for an employee to make more than the base rate of wage f the class of work being done. The contract should, of course, return a profit to the company as well as to the contractor.

To arrive at an equitable bonus system for mining operations is exceedingly difficult, and it is considered at Inspiration that it more readily len itself to abuses and injustices than a well-managed contract system. After once started, a bonus system is harder to terminate or change than a contract system, as a contract is based upon a particular piece of work and the bonus upon a class of work.

VENTILATION

The mine is ventilated in three independent sections by exhaust fans. One fan of a capacity of 140,000 cubic feet per minute at the inclined shaft furnishes ventilation for the Inspriation division. The two main hoisting shafts were originally the main intake of this division, but as mining operations have progressed and more areas have been caved, more openings to the outside have been made; this has diminished the amount of air drawn down these shafts. Much of the air drawn through the caved areas short-circuits to the fan, which materially decreases the proper ventilation of some of the areas being worked. In some cases, however, the short-circuiting air goes directly through a stope that is being worked. With so many primary entries for air an stopes scattered over a wide area the control of ventilation is difficult.

An exhaust fan of 110,000 cubic feet per minute is installed at the ol Keystone Shaft for the ventilation of the Keystone area. The air handled by this fan comes in through surface openings in worked-out stopes on the west si downcasts to the haulage level, and then upcasts through the working stopes on he east side to raises that connect to an old prospect level of the Keystone haft; here it collects and is drawn to the exhaust shaft.

The Live Oak area was more difficult to ventilate, but the air currents ave been effectively coursed through the workings. A fan of a capacity of 70,000 ubic feet over the Porphyry No. 1 shaft exhausts the return air of the division rom the 600 level. The shaft is smooth-lined with concrete. The Live Oak main haft is the main inlet; the air is drawn to the 1,200 level and from there travels hrough the levels and stopes to the 600 level. Some air short-circuits on the 600, 00, and 1,000 levels; that on the 800 and 1,000 levels is not entirely lost, but elps to ventilate the workings on the 600 level.

Usually, secondary ventilation in stopes is furnished by high pressure fans hrough 12-inch tubing. The fans are placed upon the main air courses and the ubing is run up raises or into raises that connect with the areas to be ventilated. n one area secondary ventilation is furnished by a 20,000-cubic-foot fan taking ir from the main currents.

The route of travel of the main air currents is controlled by substantial etal-covered wooden doors, either single or double; canvas-covered doorframes may e used for controlling small amounts of moving air.

Not many openings are driven primarily for ventilation, and these openings are not expected to be used over a long period. The mining of the large onnages required at Inspiration rapidly moves the zones of mining, and thus entilation currents have to be often changed to suit changed conditions. Consequently, the ventilation is not all that can be desired, but working conditions re nevertheless good. A balance must be obtained between efficient operating onditions and a prohibitive expense for independent air courses.

FIRE HAZARDS

The fire hazard underground at Inspiration is practically negligible. In the first place, all primary air inlets are of concrete construction or are in ntimbered rock areas. Also, the material mined can not start or support combustion. The mine is kept free of small debris, and oil-soaked material is placed in containers that are emptied as occasion demands. Electric wiring is heavily insulated to prevent short circuits, and the trolley wiring is exposed for inspection by everyone.

Fires starting from carbide lamps or from spontaneous combustion of oil-soaked material around the car and motor repair stations are possible. There is also the possibility of a fire's starting from short circuits in the power and lighting circuits. The time required for carbide lamps to start heavy timbers burning is considerable; smoke from timber is quickly distinguishable for long distances, and its orgin may be traced and any incipient blaze extinguished.

Water that can be used for fire-fighting is piped to all working places. Chemical fire-extinguishers are placed in known locations throughout the mine.

A complete outfit of half-hour and two-hour breathing apparatus, with the necessary auxiliary equipment for fire-fighting or use in gas, is kept at the Inspiration main shaft. This apparatus is all kept in first-class shape. A crew of 15 men has been trained in the use of all this apparatus. Their working places in the mine and also their residence is known, so that they can be easily assembled either night or day for duty with the apparatus. Extra compensation is given to these men all the time that they are in the employ of the company. Also, all the men carried as "apparatus" men are proficient in first-aid work.

Surface yards are all protected with high-pressure hydrants; the hose for connection with these hydrants is tested out each week.

SAFETY METHODS AND FIRST-AID TRAINING

The management and supervising personnel at Inspiration believe in safety; it follows, then, that the idea permeates the whole organization. To keep the idea before everyone at all times, the company employs a competent safety inspector. This inspector visits all working places, acquaints himself with any hazards that may exist, and if immediate measures are necessary gives the orders to make the place safe. In most cases the shift boss in charge of the work is notified, and he sees that the necessary work is done. The safety inspector gives frequent talks on safety to the workmen and to the bosses. These talks are at times made to the bosses only, at times to the workmen only, and at times to both groups together. The talks are given both in English and Spanish. Cooperation between the bosses, the men, and the safety inspector is close, and excellent results have been obtained.

As an incentive to the practice of safety methods, bosses are given bonuses for good safety records. A shift boss whose crew works a thousand man-shifts without a lost-time accident is given a bonus of $20. If a lost-time accident occurs, he loses credit for the shifts already worked, but a new period starts again immediately after the accident.

The foreman who has the smallest percentage of lost-time accidents among the men under his charge during a month is given a bonus of $30, and if in the succeeding month he again has the least percentage, an additional bonus of $30 is allowed.

An efficient mine-rescue and first-aid station is located in the district, and is maintained by the operating companies. This station is in charge of a very competent first-aid man. During the cooler months of the year he and his assistants give instruction in first-aid and mine-rescue, holding classes at several places in the district. Once during the season a first-aid contest is arranged. Cash prizes are awarded to all members of the teams that enter. However, the four teams having the highest percentage of skillful work are considered the winners and have the highest graduated cash rewards. To obviate the possibility of one team's winning year after year, a stipulation of the contest is that no team shall have more than two members who were members of a winning team in the previous year's contest.

SUMMARY OF COSTS

Name of Mine - Inspiration

Period Covered - Year 1928.

Tons Ore Hoisted During Period - 4,879, 646

Mining Method - Caving

1. Partial Underground Costs per Ton Ore Hoisted

	1.	2.	3.	4.	5.	6.	7.	8
	Labor	Supervision	Comp Air Drills & Steel	Power Cost	Explosives	Timber	Other Supplies	Totals of Partial Costs
Development	$0.123	$0.007	$0.019	-	$0.016	$0.040	$0.006	$0.211
Mining	.146	.007	.005	-	.017	.031	.002	.208
Transportation	.111	-	-	$0.014	.003	.013	.003	.144
Gen. Underground Exp.	.012	-	-	-	-	-	-	.012
Surface Exp.	.008	-	-	-	-	-	-	.008
TOTAL	.400	.014	.024	.014	.036	.084	.011	.583

NOTES:

Item 3 includes power for operating drills, labor sharpening drills, etc., but labor for operating drills is included with Labor shown in column 1.

Item 4 includes all power used for Underground Haulage and Hoisting only. Those two items, with Air Compression, comprise the greater part of power used. Other items of power negligible in terms of cost per ton of ore hoisted.

Items 5, 6, and 7 include Labor and sundry other expenses incident to the handling of Explosives, Timber, and Other Supplies.